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INTERIM REPORT ON TASK FORCE ON PHOSPHATE REMOVAL SLUDGES

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16. ABSTRACT

Information on dewatering properties of municipal wastewater sludges is scant and poorly organized. A Task Force has collected information on wastewater sludges with particular emphasis on sludges produced when lime, Fe^{+++}, or Al^{+++} are added for the purpose of P removal to some portion of the wastewater treatment sequence.

Data are presented on the thickening and dewatering characteristics of the sludges. Most of the information relates to the mass of sludge produced and its filtering properties.

Sludges produced when lime is added to wastewater have greater solids content after settling and dewater at greater mass rates than conventional sludges. However, mass of sludge per volume of wastewater is greatly increased. Considerable information is available on such sludges.

Sludges produced when Al^{+++} or Fe^{+++} is added to wastewater dewater more poorly than conventional sludges and sludge solids content is less. Sludge mass is greater than in conventional treatment but not as great as would be produced by lime addition. Information is clearly not yet adequate for accurately predicting dewatering properties of such sludges.

Research studies and field investigations of the dewatering properties of the sludges produced by adding Al^{+++} and Fe^{+++} to wastewater are being continued.

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INTERIM REPORT ON TASK FORCE ON PHOSPHATE REMOVAL SLUDGES

By

Joseph B. Farrell

Advanced Waste Treatment Research Laboratory

Program Element No. 1BB043

NATIONAL ENVIRONMENTAL RESEARCH CENTER
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

A Task Force has been formed within the Ultimate Disposal Section of the Advanced Waste Treatment Research Laboratory to collect and disseminate information on the dewatering properties of sludges produced by removal of phosphate from wastewater by chemical addition. The work of the Task Force is not complete. The information collected so far, however, should be useful immediately to those who are currently designing sludge handling facilities for such treatment plants. Consequently, it is appropriate to release material collected up to this time in the Task Force effort in the form of an interim report.

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Director
National Environmental
Research Center, Cincinnati

ABSTRACT

Information on dewatering properties of municipal wastewater sludges is scant and poorly organized. A Task Force has collected information on wastewater sludges with particular emphasis on sludges produced when lime, Fe^{+++}, or Al^{+++} are added for the purpose of P removal to some portion of the wastewater treatment sequence.

Data are presented on the thickening and dewatering characteristics of the sludges. Most of the information relates to the mass of sludge produced and its filtering properties.

Sludges produced when lime is added to wastewater have greater solids content after settling and dewater at greater mass rates than conventional sludges. However, mass of sludge per volume of wastewater is greatly increased. Considerable information is available on such sludges.

Sludges produced when Al^{+++} or Fe^{+++} is added to wastewater dewater more poorly than conventional sludges and sludge solids content is less. Sludge mass is greater than in conventional treatment but not as great as would be produced by lime addition. Information is clearly not yet adequate for accurately predicting dewatering properties of such sludges.

Research studies and field investigations of the dewatering properties of the sludges produced by adding Al^{+++} and Fe^{+++} to wastewater are being continued.

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The author has drawn the material of this report from a number of sources which are acknowledged in the text. Other members of a Phosphate Sludge Task Force at the Advanced Waste Treatment Research Laboratory who contributed to this report are Steven W. Hathaway, Gerald Stern, and R. V. Villiers. Mr. Hathaway conducted the field tests described in Appendices I and J, and Mr. Stern conducted the test described in Appendix G.

I. INTRODUCTION

A substantial proportion of wastewater treatment capital and operating cost is due to sludge handling and disposal. Consequently, it is important that engineers designing wastewater treatment plants have available to them reliable information on quantities and dewatering rates of sludges so that solids handling facilities can be properly designed.

Information on sludges produced in conventional wastewater treatment is widely scattered, and results of different studies are not related well to each other. Very little information is available on the sludges produced by those processes in which chemicals are added to remove phosphates.

The Advanced Waste Treatment Research Laboratory staff has endeavored to provide this necessary information in the following ways:

1. Grants and contracts aimed at obtaining comparative information on sludges, particularly phosphorus-removal sludges, have been funded.
2. Reports have been prepared that summarize information obtained on sludges in those EPA Research and Development Grants where useful sludge data have been collected.
3. Field crews have visited certain sites where interesting processes are being conducted and have obtained comparative bench-scale data on sludges.
4. Visits have been made to municipalities, and sludge data have been obtained from the plant staff.
5. The published literature has been surveyed and information of value on sludges has been extracted.
6. Memoranda have been prepared that attempt to organize the information available and to respond to specific needs.
7. Experimental investigations of sludge dewatering are being conducted at Blue Plains and Lebanon by staff of the Advanced Waste Treatment Research Laboratory.

All of these routes are being actively pursued, although the collection of information is far from complete.

The urgent need for current information has made it advisable to prepare an interim report. The objectives of this report are to provide general and specific information on the phosphate sludges, describe work currently in progress, and outline future plans for collection of information.

II. GENERALIZED ASSESSMENT OF FILTRATION RATES

A. General Approach

Smith and Eilers (1) and others (2) have presented cost-information computer programs that can be used to predict the cost of alternative processing schemes for wastewater treatment and for phosphate removal processes. These programs have included in their logic (not as input data) typical values for dewatering rates, sludge mass, additional sludges produced by phosphate removal processes, and the like. The Ultimate Disposal Section has supplied estimates to R. Smith, which he has utilized in his computer programs.

Because reliable estimates of the dewaterability of various sludges can be of substantial value to those concerned with process development, selection, and design (aside from their use in cost estimate computer programs), the information provided to Smith is repeated here in a slightly modified form.

When attempting to decide on proper values to recommend for sludge dewatering properties, one is faced with a familiar statistical problem. There is a "within-plant" variation and a "between-plant" variation. Unfortunately, the between-plant variation is very large. Consider the following hypothetical information:

	Filter yield (lb/hr-ft^2)	
	Av. (40 plants)	Std. deviation
digested mixed sludge	4.0	2.0
raw mixed sludge	5.0	3.0

The designer, who might want to use data of these types to predict a within-plant difference between filter yield of raw or digested sludge, will find this information of little value because the standard deviations are so great. The within-plant variation between raw and digested sludge is no doubt much less than indicated from between-plant data. Unfortunately, within-plant comparisons are virtually unavailable, because, generally, only one type of sludge at a given plant is dewatered.

Information relating the various within-plant sludges to each other should eventually be collected. The attempt here to estimate such relationships is based on the author's own experience, the experience of others, and the published literature. Relative values are suggested. Recommendations for absolute values are to be used only when there is no information at all to go on.

The information that follows in this section (Section II) relates only to filtration. The important area of centrifugation has been left out. One important reason for this is that there is no easy procedure (such as filter yield for filtration data) for comparing information obtained with different types, makes, and sizes of equipment. However, the appendix (Section IV) of this report describes some case studies in which centrifugation was used as a dewatering means.

Nor have lime sludges been considered in this section. Sludges produced by lime addition, even when the lime is added to the primary clarifier, contain large quantities of calcium carbonate and filter more freely than conventional or alum and iron sludges. A different approach is needed than that taken for alum, iron, and conventional sludges. Section IV of the report describes case studies where lime sludge is dewatered by various means.

B. Conventional Sludges

Because digested total sludge from a conventional primary + activated sludge plant is probably the most common sludge encountered in wastewater treatment, it has been selected as the standard against which other sludges are compared. In Table 1, the estimated relative filtration yields and conditioning costs of various wastewater sludges can be compared with a standard digested primary + waste activated sludge. These values are based primarily on discussions with experienced people and on surveys of the literature. They are for belt-type vacuum filters operated at optimum conditions, preceded by a reasonable processing sequence (e.g., thickening if clarifier sludge is dilute), and that utilize filter cloths that get satisfactory solids capture.

An average value of 4.0 lb/hr-ft^2 (19.6 kg/hr-m^2) is suggested in Table 1 for the yield for digested primary + waste activated sludge. Yield for other sludges can be estimated by multiplying the average yield by the proper factor from Table 1. If a good estimate of the yield for this or any other sludge is available, it should be used and estimates of the yields for the other sludges can be obtained by means of the factors in Table 1.

Mass of sludge produced in wastewater treatment can be estimated by means of well-established procedures (see Section III). Reduction in mass by digestion can be estimated by volatile solids reduction. Procedures are described in sanitary engineering texts. Digestion reduces mass approximately 50 percent, so the filter area needed for digested sludge will be less than that for raw sludge despite slightly higher yields for raw sludges.

Appendix A supplements recommendations in Table 1, and provides some additional comments on moisture content and elutriation.

TABLE 1

Design Factors for Filtration of Conventional Sludges

Sludge Type	Relative* Yield	Relative Cost of Conditioning**	Cake Solids Content
Raw Primary + WAS	1.4	0.7	28
Digested Primary + WAS	1.0	1.0	26
Raw Primary + TF	1.8	0.6	32
Digested Primary + TF	1.3	0.9	30
Digested Primary	2.3	0.7	33
Raw Primary	3.2	0.5	35

* Ave. yield for digested primary + WAS is estimated at 4.0 lb/hr-ft^2 (19.7 kg/hr-m^2)

** Average cost of conditioning is estimated at $10/dry ton

WAS = Waste activated sludge

TF = Trickling filter

C. Iron and Alum Sludges

Sludges produced by ferric or aluminum salts have a substantially different character than that of conventional sludges. Quantities are greater and flow properties are different. Changing the addition point of these substances in the processing scheme produces changes in the properties of the sludge.

In Table 2, the estimated filtration yields and conditioning costs of the various Al and Fe sludges can be compared with digested primary + waste activated sludge. These values are based on very limited published information, field visits, and incomplete experimental work. Information supporting the choice of values presented in Table 2 is attached as Appendix B. Estimates will be better if the absolute yields for one or more sludges listed in Tables 1 and 2 can be approximated. The factors in the tables can be used to predict other yields. If no information is available, filter yield for digested primary + waste activated sludge (when no chemicals are added to the wastewater) should be estimated to be 4.0 lb/hr-ft^2 (19.6 kg/hr-m^2).

III. QUANTITY OF PHOSPHATE REMOVAL SLUDGES

A. Iron and Alum Sludges

When iron (Fe^{+++}) or aluminum (Al^{+++}) are added to wastewater containing phosphates, a metal phosphate precipitates and the excess metal forms an insoluble hydroxide. The hydroxide forms a flocculant precipitate that carries with it other suspended solids when it settles. In addition, soluble organic material apparently is adsorbed on the precipitate and removed.

The amount and nature of additional sludge formed is a function of the point in the process sequence where the chemical is added. For example, addition to the primary clarifier causes much greater suspended solids removal than occurs when no chemical is added. Also, soluble organic material is removed. However, the biological stage that follows the primary process receives a wastewater with a much lower BOD. Consequently, the amount of biological sludge is much reduced.

Tabulations are available that present average values of the amount of sludge typically produced when Fe^{+++} and Al^{+++} are added to wastewater (3). A more precise method of predicting sludge production is needed, however, so that designers can more accurately size sludge handling equipment.

TABLE 2

Design Factors for Filtration of Sludges Produced when Al^{+++} or Fe^{+++} are Used in the Wastewater Process

Sludge Type	Relative Yield*	Relative Cost of Conditioning*
Al to Primary		
Raw Primary + WAS	1.2	1.3
Digested Primary + WAS	0.85	1.4
Raw Primary + TF	1.35	1.2
Digested Primary + TF	1.0	1.3
Digested Primary	1.05	1.0
Raw Primary	1.5	0.9
Al to Aerator		
Raw Primary + WAS	1.2	1.3
Digested Primary + WAS	0.85	1.4
Fe to Primary		
Raw Primary + WAS	1.3	1.1
Digested Primary + WAS	0.95	1.2
Raw Primary + TF	1.5	1.0
Digested Primary + TF	1.1	1.1
Digested Primary	1.2	0.8
Raw Primary	1.6	0.7
Fe to Aerator		
Raw Primary + WAS	1.3	1.1
Digested Primary + WAS	0.95	1.2

* Yields and costs are related to yield and cost obtained with digested primary + WAS when no chemicals are added to the wastewater. See Table 1 (Section II-B).

WAS = Waste activated sludge

TF = Trickling filter

A method has been developed that will yield improved predictions of sludge production for Fe^{+++} or Al^{+++} addition to the conventional processing sequence (i.e., primary treatment followed by either activated sludge or trickling filter). The chemicals may be added in primary or secondary treatment, or as an add-on or tertiary process. The experimental and theoretical basis of the method and the detailed procedure to be followed are presented in Appendix C. The method requires the following information:

complete processing sequence
wastewater characteristics (e.g., suspended solids, BOD,
    soluble organic carbon (sol. TOC))
efficiency of solids removal in clarifiers

From information collated from the literature and reasonably well-substantiated assumptions, methods are outlined in Appendix C for predicting:

chemical sludge produced
extra sludge from improved clarifier efficiency
extra sludge from removal of soluble materials by the chemicals
reduced amount of biological sludge when biological plant load
    is reduced

In this manner, total sludge production, related to processing conditions and wastewater quality, can be determined.

In the illustration given in Appendix C, where aluminum was added to the primary clarifier of a conventional activated sludge plant, sludge production (mass) was increased by 67 percent. The chemical sludge increased sludge mass 40 percent. The additional 27 percent came from organic material that would have been oxidized had it reached the activated sludge aerator. If the chemical had been added to the aerator, sludge mass would have only increased 40 percent. The greater sludge mass that results when the chemical is added to the primary clarifier must be balanced against the reduced dimensions of the activated sludge aerator, the reduction in quantity of air needed, any differences in the dewatering properties of the different sludges, and differences in chemical demand that may be dependent on point of addition.

B. Lime Sludges

When lime is utilized for phosphate removal in wastewater treatment, it is added just before the primary clarifier or after the secondary clarifier as a tertiary treatment process. As in the case of Al^{+++} and Fe^{+++} addition to wastewater discussed previously (Section III-A), average values for the amount of sludge produced have been tabulated (3). A need exists, however, for more precise information applied to specific situations.

In response to this need, a procedure has been developed for predicting the mass of sludge produced when wastewater is treated with lime in a tertiary process. The details of this procedure are detailed in Appendix D and summarized below. The method may be applied with minor modification when lime is added just before the primary clarifier.

Unlike when Fe^{+++} and Al^{+++} are added, the amount of sludge produced by adding lime depends not only on the degree of phosphate removal desired, but also on the alkalinity of the wastewater. Both the amount of sludge produced and the degree of phosphate removal achieved by raising the pH to a given level depend on the nature of the water.

The procedure in predicting sludge quantity when lime is added as a tertiary treatment is as follows:

1. From a knowledge of the desired P-residual and of the water type, estimate the pH level that must be attained.
2. From pH level and the known alkalinity, estimate lime dose (see Appendix D for correlation).
3. From amount of P removed, calculate the amount of hydroxyapatite formed.
4. From Mg removal (estimate outlet Mg from Appendix D), calculate $Mg(OH)_2$ sludge produced.
5. From Ca balance (estimate outlet Ca from Appendix D), calculate $CaCO_3$ sludge produced.
6. From the pH and alkalinity, verify that sufficient CO_3 carbonate is present in the wastewater to supply CO_3 removed in the sludge. If not, correct outlet Ca estimate.
7. Include in total sludge production the inerts introduced with the lime, as well as any sludge produced by recarbonation.

From the detailed illustration in Appendix D, chemical sludge production was calculated to be 434 mg/l when 276 mg/l CaO was added to the wastewater to produce a pH of 10.5.

To estimate the amount of sludge produced when lime is added just before the primary step, use the same procedure (with some modifications) that is used when lime is added as a tertiary treatment process. However, the correlation between pH and the ratio of lime dose to alkalinity was developed from data obtained by adding lime to secondary effluents. Because there is no assurance that it will hold as well for raw wastewater, establishing the lime dose needed by bench-scale tests would be more desirable.

Extra sludge is produced when lime is added before the primary step, because efficiency of the primary clarifier is increased substantially. From Kreissl and Westrick's review (4), suspended solids removal efficiencies in the order of 85 percent are estimated for well-designed pilot plants. This figure may be used to estimate the additional sludge solids removed in the primary clarifier by lime addition. As noted in the preceding discussion for iron and alum sludges, sludge quantity produced by "downstream" biological processes will be reduced.

The removal of dissolved organic solids by lime before the primary step appears to be less than that obtained with Al^{+++} or Fe^{+++}. Burns and Shell (5) have reported very small or negative removals. Westrick and Cohen (6) reported substantially lower removals with lime. Considering the relatively large mass of sludge from lime treatment, the small amount of dissolved organic solids precipitated in primary treatment can be neglected.

Data obtained by Burns and Shell (5) have been used to estimate whether material balance calculations similar to those described above correlate with measured sludge production. This calculation is contained in Sludge Summary No. 5 (attached as Appendix E). Measured values were about 20 percent higher than the material balance figures. A factor of safety of this magnitude should probably be used in estimating chemical sludge production.

IV. DEWATERING AT SPECIFIC LOCATIONS

A. Tertiary Treatment with Lime

1. South Tahoe. At South Tahoe, California, wastewater is treated by conventional primary clarification, followed by treatment in a waste activated sludge plant. Phosphate is removed by tertiary lime treatment to pH 11 with recarbonation. A comprehensive report describing the performance of the Tahoe plant and sludge dewatering aspects has been published (7). A summary of the information on dewatering of sludges has been prepared and is attached (Appendix F).

The tertiary lime sludge is dewatered and classified by means of solid bowl centrifuges. Sludge is thickened to 8 percent solids. It then flows at about 20 gpm to a Bird 24 x 60 inch solid-bowl concurrent-flow centrifuge (75 hp). The centrifuge is deliberately operated with high losses to the centrate in order to classify magnesium hydroxide, hydroxyapatite, and organic materials into the centrate. Consequently, the cake contains a high concentration of calcium carbonate. The cake is calcined, and its lime value is recovered. The centrate is sent to a second centrifuge, polymer is added, and solids are removed as a 30 percent solids cake.

The fact that a centrifuge removes fine, low-density solids less effectively than it removes the bulk of the solids may lead to fears that fine solids will build up in the system. This has apparently not occurred at South Tahoe.

2. Blue Plains Pilot Plant. At the Blue Plains pilot plant, a substantial amount of information was obtained on the sludges produced by treating secondary effluent with lime. This information will be published soon as a report in the EPA series (8).

Secondary effluent from the District of Columbia's Blue Plains Treatment Plant was treated with lime to a pH range of 11 to 12 for phosphate removal. Instead of utilizing second-stage recarbonation to remove excess Ca ions and recover additional $CaCO_3$, Na_2CO_3 was added to the single clarifier for this purpose. The sludge produced was continuously thickened, vacuum filtered, calcined, slaked, and recycled to the tertiary clarifier to supply the bulk of the lime demand. Information on sludge thickening and dewatering was obtained with and without recycle of reclaimed lime.

Most of the data during recycle operations were obtained at 56 percent recovery; that is, 56 percent of the active lime dose consisted of recycled lime. Recycle was approximately 3 parts (by weight) of recycled solids to 1 part of fresh lime. Lime dose consisted of 300 mg/l of active lime plus 240 mg/l of inerts.

Buildup of inerts did not affect P removal but increased solids loading through the sludge handling system. Solids content of sludge removed from the clarifier was 20 g/l for the no-recycle case and 32 g/l for 56 percent recycle.

The sludge was thickened in a 6-foot-diameter vessel equipped with pickets. Sludge thickened to 15 to 20 percent solids for both the recycle and the no-recycle case, despite the fact that the solids loading rate was over 70 percent higher for the recycle case.

The vacuum filter had too much capacity for the sludge production, so its face was partially covered and fraction immersion was greatly reduced. Because results were not typical, filtration information was obtained from filter leaf tests.

Equations for form rate for the recycle and no-recycle cases were developed by Bennett and Bishop from extensive leaf tests. These equations have been slightly rearranged here to give results in terms of yield and cycle time:

No Recycle: $$Y = \frac{(2.18)(f)^{0.5}(C)^{0.84}(p)^{0.21}}{(\theta_c)^{0.5}}$$

Recycle: $$Y = \frac{(3.28)(f)^{0.5}(C)^{0.80}(p)^{0.26}}{(\theta_c)^{0.5}}$$

where

Y = yield, lb/hr-ft^2

θ_c = cycle time (min) or reciprocal of filter rpm

C = solids concentration, wt %

p = operating vacuum, in. Hg

f = fraction submergence

These equations have been used to calculate filter yields for typical conditions:

Given $f = 0.25$ C = 15% solids

θ = 1 min. p = 15-in. Hg vacuum

No Recycle: Y = 18.7 lb/hr-ft^2 (92 kg/hr-m^2)

Recycle: Y = 29.0 lb/hr-ft^2 (142 kg/hr-m^2)

At equivalent sludge solids concentration, filter yield is evidently much larger for the recycle case.

Bennett and Bishop observed substantial cake cracking, which reduced vacuum across the filter. Nevertheless, solids contents from 30 to 40 percent were generally obtained. They also noted that after a process upset, which caused biological solids to carry over into the tertiary treatment system, filter yield deteriorated drastically. Filtration was possible, however, without the need for chemical conditioning.

Considerable additional detail will be available in Bennett and Bishop's report.

3. Butler, Indiana. At Butler, wastewater is treated in a conventional primary + trickling filter plant. Phosphate is removed by tertiary lime treatment in a reactor-clarifier to pH 10. Total P removal is about 80 percent. Sludge is not dewatered but is pumped to a lagoon.

Butler differs from South Tahoe and Blue Plains in that the wastewater is much harder and its Mg content is higher. Ordinarily, good P removal is achieved at a lower pH in water of this type than in soft low Mg water such as at Blue Plains and South Tahoe. Since required P removal was only 80 percent, a pH of 10.0 was sufficient to obtain satisfactory performance.

The report of a field trip to Butler to determine dewaterability of the tertiary sludge produced is attached (Appendix G). Results indicated that sludge leaving the reactor-clarifier contained about 8.4 percent solids. Overnight settling increased this figure by only 10 percent. Lagoon sludge, however, even after only a few days settling, was about 17 percent suspended solids. Fresh sludge from the reactor-clarifier could be filtered at 5.6 $lb/hr\text{-}ft^2$ at a cycle time of 2.9 min (33 percent immersion). Higher yield could be achieved at lower cycle times, but this would produce cakes less than 1/8-inch thick, which could give problems with cake release.

Sludge was mostly mineral in nature. Percent volatile solids was under 10 percent. Mg content of the sludge was low. At higher pH, more Mg would have been precipitated, which could have produced a poorer filtering sludge.

B. Primary Treatment with Lime

1. Contra Costa. The Contra Costa Sanitary District, Walnut Creek, California, has carried out a pilot and plant-scale evaluation of an integrated process for handling sludges produced by adding lime to primary wastewater treatment. The details of this work can be found in a recent EPA publication by Parker et al., of Brown and Caldwell Consulting Engineers (9).

The Contra Costa process scheme comprises lime flocculation (with polymer or ferric chloride) followed by primary sedimentation, activated sludge treatment under conditions so that nitrification is achieved, denitrification aided by methanol addition, and chlorination. Waste activated sludge is recycled to the raw sewage so it is removed from the primary clarifier along with the combined chemical-primary sludge. Denitrification sludge is also returned to the incoming raw sewage, but its amount is negligible.

In addition to investigations of process performance, engineering studies were made to evaluate (a) predictive methods for estimating sludge production, (b) the degree of thickening achieved in primary clarification, (c) the utility of a two-step procedure in which sludge is centrifugally classified to recover calcium carbonate and the centrate is centrifuged again to remove solids, and (d) anaerobic digestion of the first-stage centrate.

Sludge mass predicted from material balance calculations based on the chemical analysis of influent and effluent wastewater checked satisfactorily with measured sludge mass. Operation at pH 10.2 produced a clarifier sludge of about 4.0 percent solids. At pH 11, a higher sludge solids could be attained. Centrifugal classification achieved a high recovery of calcium carbonate (about 80 percent) in relatively dry cakes (42 to 57 percent solids). Solids remaining in the centrate could be removed by polymer-assisted centrifugation at recoveries as high as 90 percent. Results were not as good at pH's greater than 11. The centrates from the first centrifugation could be anaerobically digested, although volatile solids reduction was lower than for conventional sludge processing. In addition, precipitated Mg dissolved into the digester supernatant. Return of supernatant to process would increase lime demand and Mg would be precipitated again (disposal of supernatant by separate treatment or return to the secondary process would avoid the problem).

2. Eimco at Salt Lake City. Eimco Division of Envirotech has conducted a pilot plant investigation of a wastewater treatment system in which chemicals are added in the primary step and soluble organic material is removed by powdered activated carbon. A progress report on this investigation has recently been published (10); a summary of the sludge information from this report is attached (Appendix E). Eimco's investigation of both sludge handling and carbon treatment has been continued, and a report of an additional year of effort is in preparation.

Comparisons of sludge mass, calculated from chemical analyses of the clarifier input and output, wastewater, with measured mass, calculated from sludge volume and solids content, showed reasonable agreement. For Fe^{+++} added to the primary clarifier, measured mass was 20 percent higher than the calculated value. Part of the reason could have been the failure to include removal of soluble organics (no soluble TOC data were obtained). For Al^{+++} added to the primary clarifier, calculated mass (including soluble organic material) was virtually the same as the measured mass. For lime, the measured values averaged 20 percent higher than the calculated values.

Thickening and filtration data were incomplete for iron and for alum; however, data with lime were much more complete. After 24 hours thickening, sludges produced when wastewater was raised to pH's greater than 11.5 thickened to 2.0 to 9.8 percent solids (median of 6 measurements was 7.0 percent). For pH values less than 11.0, sludge thickened to 9.0 to 18.0 percent (median of 7 measurements was 14.0 percent).

Filtration yields were obtained for high and low pH operation. No polymer was needed. For low pH sludge at the median thickened solids content (14.0 percent), maximum filter yield was 6.0 $lb/hr\text{-}ft^2$ (29.4 $kg/hr\text{-}m^2$). For high pH sludge at the median thickened solids content (7.0 percent), maximum filter yield was 3.0 $lb/hr\text{-}ft^2$ (14.7 $kg/hr\text{-}m^2$).

Note that the Salt Lake City wastewater is high in Mg. Operation at pH greater than 11.5 precipitates much more Mg than is precipitated at pH less than 11.0. Since $Mg(OH)_2$ is a flocculant precipitate, this could account for the low solids content of thickened sludge from high pH operation.

3. Cleveland Westerly. Extensive pilot plant work was conducted at Cleveland's Westerly plant before preparing a design for a physical-chemical treatment plant. A report describing this work, prepared by Zurn Environmental Engineers and Battelle-Northwest, has been summarized and attached (Appendix H).

Most of the work was done with lime added before the primary clarifier to reach a pH of 10.5. Sludge was dewatered with the use of a Bird pilot plant centrifuge and a Eimco belt-type pilot plant vacuum filter.

Sludge solids content leaving the clarifier was between 6 and 14 percent solids. Thickening before centrifugation was not needed. Solids recovery in the centrifuge was not adequate without polymer addition. However, doses of less than 2 lb/ton gave recoveries of 95 percent at good flow rates. Solids content of the sludge cake ranged from 20 to 28 percent.

The lime-primary sludge could be filtered without polymers, but performance was improved greatly by adding small quantities of polymer. Filtration yields in excess of 10 lb/hr-ft^2 (48.9 kg/hr-m^2) could be achieved readily. Recoveries were in the order of 95 percent. Sludge solids ranged from 20 to 35 percent with 28 percent a typical value.

4. Canadian Experience. The Province of Ontario's Ministry of the Environment has carried out a number of plant-scale testing programs at sewage treatment plants. This work has been summarized in articles by Van Fleet et al. (11), Boyko and Rupke (12), and Knight et al. (13). Pertinent information from Boyko and Rupke's paper is included below.

The use of lime in secondary plants (all activated sludge) increased sludge production from a normal level of about 180 mg/l to 460 mg/l with the addition of 200 mg/l lime (probably as $Ca(OH)_2$). Sludge solids content increased from 4.5 to 9 percent. In primary plants, sludge production increased from 80 mg/l to 240 mg/l. Sludge solids content increased from 7 to 15 percent.

Some difficulty was encountered with anaerobic digestion because of erratic dosage with high pH sludge. Subsequent studies have shown that holding the sludge longer in the clarifier reduces sludge pH. Digester operation is then normal except for the high solids content of the sludge.

Raw lime sludge was dewatered successfully in a continuous, solid-bowl, conveyor-type centrifuge at the Newmarket/East Gwillimbury plant (14). A detailed investigation showed that high recoveries could be achieved with polymer addition, and at these high recoveries, phosphorus removal from the centrate was also high (15).

With lime added to the primary clarifier of a conventional plant (primary + activated sludge), filter yield increased from 5.2 to 7.2 lb/hr-ft^2, and conditioning costs (lime + $FeCl_3$) fell from $16/ton to $11/ton. Cake solids content was 29 percent.

C. Alum and Iron Salts

1. Blue Plains. Alum was added to the 300 mgd wastewater treatment plant at Blue Plains, Washington, D. C., for several months. At this plant, primary treatment is followed by high rate activated sludge. Waste activated sludge is combined with sludge withdrawn from the clarifier, and the mixed sludge is thickened and digested. The digested sludge is elutriated in two stages with the use of polymer to retain solids. The sludge is filtered with the use of polymer and ferric chloride for conditioning. The following account of the alum addition tests is based on discussions with plant operating personnel.

The alum was added to the aerator in gradually increasing doses until the average dose level was 40 mg/l of alum (9.1 percent Al). This represents a relatively high level of aluminum in the sludge because the Blue Plains wastewater is weak.

Alum addition did not affect thickening. Sludge leaving the thickeners remained at 7.5 percent solids. Digestion was likewise unaffected. Suspended solids leaving the digesters remained at 3.5 percent. Elutriation could be carried out, but a higher polymer dose was required to retain the suspended solids. Chemical costs for elutriation increased from $3/ton before alum addition to $7/ton during the test. Filter yields were about the same but solids content of the cake dropped from 23 to 20 percent. Polymer condition cost for filtration, which had been $6/ton, rose to $7/ton.

2. Pomona. At Pomona, California, a physical-chemical plant has been in operation to produce a feed stream for a long-term test of carbon columns. The wastewater has been treated in a primary clarifier with 22 mg Al^{+++} per liter. The report of a field test conducted to determine the dewatering characteristics of this sludge is attached (Appendix I).

Gravity thickening tests showed that without polymer, the sludge settled slowly. Thickening rate to produce a 4 percent solids sludge was extremely low--6.6 lb/day-ft^2 (32 kg/day-m^2). With polymer addition, rate increased to 20 lb/day-ft^2 (98 kg/day-m^2) with 2 lb/ton (1 g/kg) of 837-A (American Cyanamid anionic polymer) and to 70 lb/day-ft^2 with 6 lb/ton (3 g/kg). Filtration rates with 12 percent lime and polymer were less than 2 lb/hr-ft^2 (9.8 kg/hr-ft^2) at the low cycle time of 2 minutes. However, the sludge employed was only 2 percent solids. The rate would be expected to double if 4 percent solids sludge were available.

One of the reasons this field test was conducted was to verify experimental results currently being obtained at Lebanon, Ohio. The Lebanon work is showing that sludges produced when Al^{+++} or Fe^{+++} is added to the primary clarifier settle poorly and have lower filter yields than conventional sludge. The Pomona field test corroborated these findings.

3. Grand Rapids. The addition of ferric chloride at various points in the process was studied at Grand Rapids, Michigan. The Grand Rapids plant has a conventional primary clarifier followed by activated sludge. The ferric chloride was added in three different modes: to the primary clarifier alone, split between the primary clarifier and the aerator, and to the aerator alone. An investigation of sludge dewatering was not part of this project. It was hoped, however, that the filter yield data routinely collected at this plant could be related back to the chemical dosing conditions.

Monthly average filter yields, cake solids, and chemical costs were supplied by Grand Rapids staff (Figure 1). Large fluctuations in all three filtration variables are evident; however, they are not correlated with ferric chloride dosing. This finding was predicted by Grand Rapids staff who observed that the basic nature of the sludge can change from month to month and that necessary maintenance can cause step changes in performance. Some of the interferences noted at Grand Rapids were:

a) periodic dumping of lime sludge from a water plant into the wastewater collection system
b) performance changes in digestion
c) acid cleaning of filter cloths
d) cleaning of interior piping of vacuum filters
e) replacement of vacuum system
f) periodic switchover from the incinerators (which had a lower capacity than the vacuum filters and needed a dry cake) to landfill (where maximum output was desired and a dry cake was not so important).

The Grand Rapids experience suggests that, to get reliable information on the changes in sludge filtration properties caused by process changes, the filter system should first be placed in first-rate operating condition.

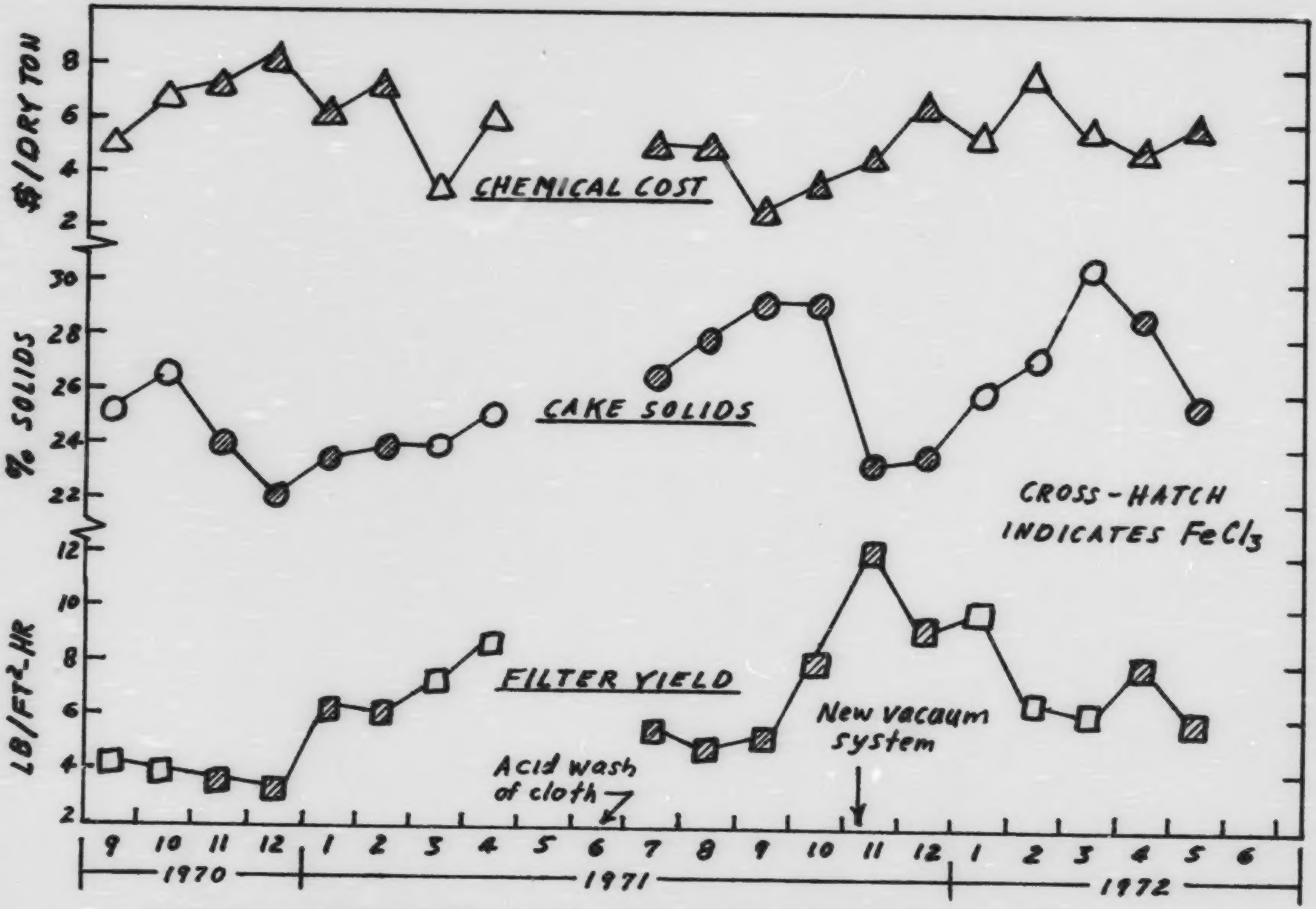

FIG. 1 : EFFECT OF $FeCl_3$ ADDITION AT GRAND RAPIDS

Then, with the filters performing at their optimum, get baseline data. A comparison would be invalid if, after a process change is made, filters are fine-tuned to give optimum performance, and are compared with a baseline period during which there was either no pressure to get optimum filter yield or the equivalent was not in top operating condition.

4. Canadian Experience. Reference has been made earlier (Section IV-B-4) to the work reported by Ontario's Ministry of the Environment (11, 12, 13). Pertinent information concerning alum and iron salts from the summary paper (12) is included here.

When metal salts were utilized in secondary plants (almost all were activated sludge), the dry solids sludge production increased by 5 to 25 percent. Sludge concentration range dropped to 3.5 to 5.0 percent solids from the normal range of 4.0 to 5.5 percent solids.

In primary plants, sludge production increased drastically because of increased solids capture. An increase of 100 percent can be expected and a 20 percent reduction in sludge solids concentration can be expected.

In all cases where metal salts were used to precipitate P, normal digestion was observed. The problems that developed resulted from increased hydraulic and volatile solids loading.

Filtering rates were approximately halved for a primary plant when alum was added. Lime and $FeCl_3$ conditioning costs increased from $3.10 to $9.50 per ton. Solids content of cake dropped from 31 to 19 percent. For a secondary plant with alum added to the primary, the filtering rate fell from 5.2 to 4.8 lb/hr-ft^2 (25.5 to 23.5 kg/hr-m^2), and conditioning chemical cost increased slightly. Cake solids content was 15.9 percent with alum addition.

5. Chapel Hill. Chapel Hill is a 5 mgd trickling filter plant which is conveniently split into two parallel treatment plants, each with its own primary clarifier, high rate trickling filter, and final clarifier. During an experimental program, the wastewater from one train was dosed with alum for P removal, just before it entered the final clarifier. The results from a field trip to this unique facility to determine the impact of alum addition on the wastewater sludge have been detailed (Appendix J).

The results indicated that the sludge from the secondary clarifier following the alum-dosed train was essentially unfilterable, even with polymer addition. Since this was a high-rate filter with substantial recirculation before the clarifier, the sludge was very low in organic matter. The secondary clarifier sludge from the control train showed reasonable filter yields. Secondary sludges from both trains were recirculated to their respective primary clarifiers and removed as mixed primary-secondary sludges. Filter leaf tests showed that there was no substantial difference in the filter yields from the two trains.

Data supplied by University of North Carolina staff, who operate the plant, indicated that 4.75 pounds extra sludge was generated per pound of Al added. They also indicated that difficulty was encountered during the alum tests in their two-stage digester. The solids content of the supernatant leaving the second digester was unusually high.

V. FUTURE WORK

A review of the information presented in this report shows that considerably more data are available on the dewaterability of sludges produced by adding lime to the primary clarifier than is available for sludges produced by aluminum or iron salt addition.

The amount of information available on lime sludges is such that there appears to be no pressing need for additional experimental work. A need still exists to organize the information now available from a number of case studies into an organized body of design information.

Aluminum and iron sludges are presenting serious dewatering problems. Information is needed on the dewatering rates that can be expected with the usual dewatering devices, how performance of these devices can be improved, and what process equipment is most suitable for new plants or for upgrading dewatering capabilities of existing plants.

To obtain needed information, visits are planned to a number of plants where phosphate removal is contemplated or in use. These will be field trips with bench-scale equipment or with a trailer equipped with pilot-scale dewatering devices. In addition, sludge dewatering studies are underway at Lebanon, Ohio, and at the pilot plant at Blue Plains, Washington, D.C. Vacuum filtration, centrifugation, and flotation thickening of aluminum and iron sludges are being investigated.

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APPENDIX A

Information Supporting Recommended Relative Filter Yields for Conventional Wastewater Sludges*

Background

To the writer's knowledge, there is no definitive published information comparing filtrability of raw sludge and digested sludge originating from this raw sludge. No information is available comparing digested sludge with the same digested sludge after it has been elutriated.

Harrison(1), commenting on primary sludges, points out that "Our experience in many plants indicates that digestion yields a sludge that is slightly more difficult to dewater than raw primary sludge." He states that costs are slightly higher and yields slightly lower.

If two-stage digestion is practiced, sludge solids are generally substantially higher than obtained by thickening raw sludge. Harrison's comment does not mention solids content of the sludge. Presumably, he means that at the solids content which reaches the vacuum filter (after a well-designed processing sequence), raw sludges dewater at a little higher rate and a little lower chemical cost than digested sludges.

Parenthetically, it should be noted that filter operators are not necessarily pleased with a very high solids sludge. Conditioning agents do not mix in well, and the flocculated mass can become too stiff to flow properly. Dilution at the filter station is occasionally practiced.

Estimated Values

Estimated values are given in Table 1 (see Section II-B). The estimates have been given in terms of ratios. They are based on the assumption that the sludge is processed properly before filtration (e.g. thickening for raw sludge, two-stage digestion for digested sludge).

The values presented in Table 1 were estimated on the basis of the ratios of filter yields shown below:

*Information was extracted from a NERC-Cincinnati Memorandum, J. B. Farrell to Record, Mar. 26, 1973.

raw/digested = 1.4/1
(est. std. dev. of ratio = 0.2) (1)

primary/(primary & WAS) = 2.3/1
(est. std. dev. of ratio = 0.4) (2)

(primary & TF)/(primary & WAS) = 1.3/1
(est. std. of ratio = 0.2) (3)

Estimates of standard deviation of the ratios have been made on the basis of engineering judgment. Data are sorely needed to verify these estimates.

An appropriate average filter yield for digested primary and waste activated sludge has been estimated at 4.0 lb/hr/ft^2. This value can vary over a wide range, so much so that the distribution about the mean is no doubt skewed. The logarithm is often used to normalize such distributions. Estimated error is expressed below in terms of the logarithm.

$$\log_{10} \text{(ave. yield)} = \log_{10} 4.0 = 0.60$$

$$\text{est. std. dev. of } \log_{10} \text{(ave. yield)} = 0.18$$

Some shortcomings of the tabulated numbers are evident. No influence of solids content is indicated, although it is well known that, up to about 8% solids, filter yield is proportional to solids content. It must be presumed that appropriately designed thickeners are used. It becomes clear then that when a filter yield is chosen, there are implicit assumptions about the operations upstream.

Elutriation is not included in Table 1. Elutriation would reduce lime demand substantially. According to Mogelnicki(2), polymer required for conditioning would be reduced as well. In his opinion, elutriation is virtually a necessity for some digested sludges.

No indication of differences in solids content of sludge cake is given. This is of importance when the sludge is to be incinerated. Teletske's data (3) indicates that digested primary and waste activated sludge would have a solids content of about 28% and for primary and waste activated sludge, it would be about 30%. *

It is anticipated that revisions to the recommended values in this report will be needed as more references are uncovered and as new information is generated. Addressees and other readers who have such information are encouraged to communicate with the writer.

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* Slightly lower values are suggested in Table 1.

Literature Cited

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(2) Mogelnicki, S., Comment at Los Angeles Technology Transfer Session, November 1972. (Mr. Mogelnicki is one of Dow Chemical's experts on sludge conditioning).

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APPENDIX B

Information Supporting Recommended Relative Filter Yields for Sludges Produced by Al or Ferric Addition in the wastewater Treatment Process*

BACKGROUND

Al^{+++} - Data are becoming available (1) on Al^{+++} addition to the aerator at the full-scale plant at Blue Plains, Washington, D. C. Digested primary + WAS filters at approximately the same rate (i.e., yield) obtained before Al^{+++} addition, but moisture content is higher. Previously, moisture content was 77%; now it is running 80%. Al^{+++} dose is only about one-fourth its ultimate level; consequently, much greater effects are expected. However, the ratio of Al to original sludge solids is nearly one-half the ultimate value expected at other locations, where sewage would have higher solids that the District's weak sewage.**

Data are available from the Little River Plant in Windsor, Ontario (2) on the relative effect of addition of 150 mg/l alum to the primary. This plant has conventional primary plus activated sludge treatment. Filter yield dropped from 5.2 $lb/hr\text{-}ft^2$ to 4.7 $lb/hr\text{-}ft^2$, a 10% drop, and conditioning chemical cost rose from $16.08/ton of dry solids to $17.78, an increase of 10%. Limited work by Eimco (3) at Salt Lake indicated very poor filter yields when alum was added to the primary. The reduction in the quantity of biological solids which occurs when alum is added to the primary must be responsible for the relatively small drop in filter yield at the Little River installation.

Fe^{+++} - There is a great deal of Dow work which indicates in a general fashion that iron addition improves filterability. Our own pilot scale work at Lebanon, Ohio indicates that decreases rather than increases are to be expected. Decreases may be the result of high iron dosages coupled with low suspended solids in the influent sewage.

I have analyzed the data available from Grand Rapids where Fe^{+++} was added to the primary at a level of about 20 mg/l. Grand Rapids has a conventional primary + activated sludge plant. These data do not show differences clearly attributable to the use of iron. Other variables were causing changes which masked any effect of Fe.

It is generally thought that the use of iron produces a sludge which filters somewhat better than would be obtained with alum.

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* Information was extracted from a NERC - Cincinnati, Memorandum, J. B. Farrell to Record, April 4, 1973.

Estimated Values

Estimated values are presented in Table 2 (see Section II-C). Rather than presenting the estimates as absolute values, they have been given in terms of ratios. The objective of this procedure is to indicate that the predictions should be related to properties of the sludge as it now exists, if this information is available. All figures are based on the assumption that the sludge has been processed properly before filtration.

The estimates in Table 2 are based on the judgments shown in the following table:

Sludge	Multiplying Factor	
	Al	Fe
Primary + WAS	0.85	0.95
Primary + TF	0.75	0.85
Primary	0.47	0.51

The table above shows factors by which the filter yield before chemical addition must be multiplied to predict the new yield. For example, consider that Al is going to be added to the primary of a plant with a trickling filter, the new mixed sludge would have a filter yield 0.75 times the yield before chemical addition. This tabulation assumes that:

1) The point of addition of Al or Fe (i.e., either before the primary or to the aerator) does not change the filterability of the mixed sludge, and --

2) The effect of Al or Fe addition is the same for raw sludge as for digested sludge.

The figures in Table 2 (Sec. II-C) can be arrived at by multiplying the figures in Table 1 (Sec. II-B) by the appropriate factor in the above table.

Critical consideration of the estimated values is invited. Additional data on which to base revised values will be welcome.

Literature Cited

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APPENDIX C

Increase in Sludge Mass When Al or Fe are Used in Wastewater Treatment Processes*

I. INTRODUCTION

Aluminum and ferric salts are utilized in wastewater treatment primarily to remove phosphates. One side effect is a substantial increase in the mass of sludge produced. The reasons for the increase in mass are as follows:

A. removal of suspended solids in clarification is increased

B. some colloidal solids not measured as suspended solids are removed

C. phosphates react with the Al or Fe* and are precipitated

D. excess Al or Fe form hydroxides and are precipitated

Estimates of sludge production have been made on a purely empirical basis merely by noting increases in production at plants where Al or Fe are used to remove phosphate. Adrian and Smith (1) report some of these values. Because data were obtained for plants with a wide range of performance and sewage characteristics, the method is useful only for rough approximations.

The objective of this memo is to present a procedure for estimating sludge production when Al or Fe are added in the process steps which will be sufficiently accurate for most design purposes. The procedure is developed for conventional treatment; that is, the plant has a conventional primary followed by a trickling filter or activated sludge. The Al or Fe is added at appropriate points in the process. The procedure relates sludge production to chemical dose, sewage strength and anticipated efficiencies of processing steps.

II. DEVELOPMENT OF METHOD

A. Chemical Sludge

The chemical sludge may be calculated by assuming that the metal added reacts first with the phosphate which is removed and that any excess forms the hydroxide. The calculation is illustrated in Table I. The illustration shows that at approximately the same atomic ratio of metal to phosphorus, 48 percent more chemical sludge is predicted for iron addition than for aluminum addition.

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*All references to Fe refer to iron in the ferric form.

*Information was presented previously in a NERC-Cincinnati, Memorandum, J. B. Farrell to Record, Aug. 23, 1973.

Sludge production is related in the table to mass of P removed or liter of sewage treated. These are the most useful procedures when sludge mass is desired. However, it is frequently convenient to relate sludge mass to the mass of Al or Fe added. Table I shows the following values for the ratio of sludge mass to metal dose as the metal/P atomic ratio increases from zero to infinity:

Al: 4.52 to 2.89 mg sludge/mg Al (1a)

Fe: 2.70 to 1.92 mg sludge/mg Fe (1b)

Information to verify these calculated values is scarce. Isgard (2) states that the additional amount of sludge may be calculated from the following relationships:

sludge (mg/l of wastewater) = (4) (Al dose, mg/l) (2a)

sludge (mg/l of wastewater) = (2.5) (Fe dose, mg/l)(2b)

Isgard does not elaborate on the source of this information although it probably was drawn from Swedish **practice** at the time. He does not state whether additional mass from improved suspended and dissolved solids removal is included in his figures. He reports in his paper that the great majority of plants in Sweden were adding chemicals as a post-treatment after biological treatment. Consequently, it may be presumed that his figures indicate the total increase in sludge mass from Al or Fe added to the final effluent from a biological treatment plant.

Mulbarger and Shifflett (3) estimated additional sludge produced by alum addition to the activated sludge process. They report 4 to 3 mg addition solids per mg of Al as dose level increased from 10 to 20 mg Al/l.

Farrell (4) has reported chemical sludge production when alum was added to secondary effluents. He observed the following relationship:

chemical sludge (mg/l of wastewater)=(5.2)(Al dose, mg/l)   (3)

Al/P atomic ratio range: 2.0 to 2.8

This is about 20 percent higher than Isgard's figure and about 45 percent higher than indicated in Table I for the stoichiomitric relationship.

Data available, thus, indicate chemical sludge mass higher than the values represented by the simple stoichiometry indicated in Table I. There is reason to believe that chemical sludge production could be higher than the stoichiometric values because other cations (such as heavy metals) and anions can be incorporated into the complex ligand structures of the aluminum and ferric hydroxides. Consequently, the writer recommends that with either Al or Fe sludge mass be estimated to be 35 percent higher than the simple stoichiometric values.

B. Biological Sludge

Biological sludge is produced and wasted in the conventional activated sludge process and the trickling filter process.

Smith (5) reports the following equation for excess sludge production in the conventional activated sludge process:

$$\frac{W_v}{M} = 0.79\frac{F}{M} - 0.0714 \qquad (4)$$

where W_v = lb volatile suspended solids produced per day

M = lb mixed liquor volatile suspended solids in the aerator

F = lb BOD* removed per day

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*All references to BOD refer to the 5-day BOD.

Rearranging this equation,

$$\frac{W_v}{F} = 0.79 - \frac{0.0714}{F/M} \qquad (5)$$

The equation now gives the mass of volatile solids produced per unit mass of BOD removed (W_v/F) as a function of the food to mass ratio.

A joint report by the City of Austin and the University of Texas (6) states that 50 percent of the sum of the BOD and suspended solids fed to a trickling filter is converted to waste sludge.

If suspended solids and BOD concentrations in the wastewater as it enters the biological treatment step are known, sludge production can be estimated by means of the above relationships.

C. Removal of Sewage Solids by Chemicals

Suspended solids and dissolved solids in the wastewater are removed by chemical treatment. Sludge mass is increased by the direct contribution of the mass of removed solids.

Kreissl and Westrick (7) have summarized data on suspended solids removal from well-designed physical-chemical pilot plants. For an average sewage and properly designed clarifiers, suspended solids removal of 85 percent can be achieved. If the sewage is high in suspended solids, removals will be better. This figure is substantially higher than the 50-75% removal range suggested by Black and Veatch (8). These latter authors do not give the sources of their information. It is likely that their survey included plants where chamicals were added to an existing facility which might have been overloaded or poorly designed.

The mass of sludge produced from the suspended solids removed is calculated directly by multiplying the change in suspended solids concentration by the volume of sewage.

Kreissl and Westrick (7) also cite experimental work which indicates that an appreciable mass of dissolved materials (i.e., filtrable through a 0.45 μm membrane filter) is removed by chemical treatment. The following table presents this information along with data collected by Farrell on clarification with alum.

Source	Percent Removals					
	Fe		Al		Lime	
	SCOD	STOC	SCOD	STOC	SCOD	STOC
Eimco						
pilot plant(9)			40	30	-10	-10
laboratory(9)				ca.30		
Friedman et. al.(10)		30				
Farrell				27		
Westrick and Cohen(11)	45	42				

Farrell's results represent the average removal obtained in seven batch experiments in which raw sewage was treated with alum in a small clarifier (150 liter batches). Al/P atomic ratio ranged from 1.6 to 2.8 and removals from 20 to 32 percent. Based on the above data, it is assumed that soluble TOC removals will average 30 percent. Data are scant for COD and none are available for BOD. It is assumed, however, that removals will be the same for STOC.

The mass of sludge associated with the soluble TOC removed is obviously more than the carbon content. It is estimated that, on the average, the soluble compounds removed by Al and Fe treatment will average 40 percent carbon on a volatile solids basis. This figure is in accord with the carbon content of compounds tested by Schaffer et.al. (12) in developing the TOC test for wastewaters. Thus, to obtain an estimate of the mass of sludge (volatile basis) produced, TOC removed should be multiplied by 1/0.40 or 2.5.

If soluble COD removed or soluble BOD removed is known, the problem is more difficult, primarily because the relationship between mass and COD or BOD

Kreissl and Westrick (7) also cite experimental work which indicates that an appreciable mass of dissolved materials (i.e., filtrable through a 0.45 μm membrane filter) is removed by chemical treatment. The following table presents this information along with data collected by Farrell on clarification with alum.

Source	Percent Removals					
	Fe		Al		Lime	
	SCOD	STOC	SCOD	STOC	SCOD	STOC
Eimco						
pilot plant(9)			40	30	-10	-10
laboratory(9)				ca.30		
Friedman et. al.(10)		30				
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If soluble COD removed or soluble BOD removed is known, the problem is more difficult, primarily because the relationship between mass and COD or BOD changes as the degree of oxidation of the sewage changes. For a secondary effluent, volatile mass/COD is generally considered to be about 1.5 (13). Assuming the BOD is about 70 percent of the COD, volatile mass/BOD is 2.15. For raw sewage, which has a low degree of oxidation, the COD is expected to be higher for a given mass. Volatile mass/COD for a raw sewage is estimated to be 1.1 (approximately 10 percent lower than lowest value found by Bunch et. al. (12) for a secondary effluent). Volatile mass/BOD would be about 1.6.

There is clearly a need for data to substantiate these estimates. Much work has been done trying to relate BOD, COD and TOC to each other. It is suggested that experimental work be done to relate all three to the mass of volatile solids. Of the three measures, the ratio of mass to TOC is potentially the most useful since it probably will show much less variation as the sewage progresses through treatment than the ratio of mass to COD or BOD.

In the above discussion, mass referred to was the mass of volatile solids. To obtain total mass, non-volatile solids must be included. It is estimated that the ash content of these soluble solids is about 15 percent. Mass of volatile solids should be multiplied by 100/(100-15) = 1.18 to get total solids.

The calculation of sludge mass resulting from removal of soluble material will require information on the absolute value of soluble TOC, COD or BOD. These values are rarely measured. An examination of Eimco's data (9) where both SCOD and STOC were measured showed that the ratios of soluble to total COD and TOC in the influent sewage were 0.30 and 0.38 respectively. Farrell's data on Lebanon and Batavia effluents showed an STOC/TOC ratio of 0.64. If data on soluble values of TOC or COD are not available, soluble TOC or COD may be estimated to be 50 percent of the total TOC or COD.

The correlations for predicting sludge production require information on the total BOD removal. Kreissl and Westrick (7) indicate that total BOD, COD and TOC reductions are about the same and range from 50 to 85 percent depending on clarifier efficiency. Removals of 65 percent is herein chosen as a representative figure.

III. Calculation Procedure

The calculation procedure is described for various process addition points for the chemical and is illustrated with a specific example (Sec. III - D below).

A. Chemicals Added to Primary

The chemical sludge is calculated on the basis of the phosphorus level and the chemical dose in the manner illustrated in Table I (Estimated mass should be increased by about 35 percent)(see Section II A).

Additional suspended solids removals in primary treatment are estimated using quantities derived from Kreissl and Westrick's summary paper (see Section II C). The additional suspended solids mass removed should be added directly to the sludge mass.

Mass resulting from dissolved solids removal has to be estimated indirectly from soluble TOC, COD or BOD removal. Factors to be used in predicting mass have been discussed in Section II C. Equations relating soluble TOC, COD and BOD input levels to mass of soluble solids removed are presented below:

$$\begin{aligned}\text{Total mass of soluble solids removed (mg/l)} &= STOC_{in}(mg/l)\times 0.30\times 2.5\times 1.18 && (6a)\\ &= SCOD_{in}(mg/l)\times 0.30\times 1.1\times 1.18 && (6b)\\ &= SBOD_{in}(mg/l)\times 0.30\times 1.6\times 1.18 && (6c)\end{aligned}$$

Equations 6b and 6c apply only to influents before oxidative processes such as the activated sludge process.

Estimates of total TOC, COD or BOD removals are needed to estimate the loading on the biological processes which follow chemical treatment. However, this information is not needed for estimating sludge formation in the chemical treatment step.

B. Chemicals Added to Activated Sludge

The chemical sludge is calculated in the manner described in Section II A.

The addition of chemicals to the activated sludge process may produce a significant increase in BOD and suspended solids removals. This is particularly true of a high rate activated sludge plant or an overloaded plant. However, for a well-designed standard rate plant which typically could produce an excellent BOD and suspended solids removal, addition of chemicals will produce very little additional sludge other than the chemical sludge itself. This writer recommends that for a standard rate plant no increase in mass be included for additional suspended solids. For special cases such as an existing high rate plant, judgment will have to be made based on available information.

C. Chemicals Added After Biological Treatment (Tertiary Treatment)

The chemical sludge is calculated as in III a. If the tertiary treatment follows a standard rate activated sludge plant, additional sludge from improved suspended solids and dissolved BOD removal can be neglected. For a trickling filter plant, the additional mass removed could be important. For example, Brown (14) reports a substantial improvement in BOD and solids removal in a high rate trickling filter plant as a result of alum addition before the final clarifier. In one series of runs, overall BOD_5 removals increased from 73% to 91% and suspended solids removal increased from 70% to 84%.

At Richardson, Texas (15), under conditions where the final clarifier was not hydraulically overloaded, alum added after a standard rate trickling filter brought BOD and suspended solids from the 15-20 mg/l levels to levels below 10 mg/l.

Estimates based on Brown's figures or the Richardson results can be used to calculate additional sludge brougnt down with the chemical sludge.

D. Illustrative Calculation

Sludge mass is calculated for a plant utilizing primary treatment with aluminum introduced before clarification, followed by standard rate activated sludge. Details of the calculation are presented in Table II. The existing plant is a properly designed plant operating within its design limits, which is changed only by introduction of a means to introduce the chemical and flocculate it before primary clarification.

Calculated raw sludge masses for the plant before and after chemical introduction are presented in Table II and are summarized below:

	No Chemical	Chemical	% Increase
Primary Sludge (mg/l)	120	324	170%
Waste Activated Sludge (mg/l)	94	33	-65%
Total Sludge (mg/l)	214	357	67%
Total Sludge Less Chemical Sludge (mg/l)	214	273	28%

It is clear that chemical addition produces a substantial increase in the total sludge mass, 67% in our illustration. The increase is greater than just the amount of chemical sludge because, in the "no-chemical" case, there is substantially more conversion of organic substances to carbon dioxide and water in its much larger activated sludge plant.

For a plant in which the chemical is added to the activated sludge process, the increase in mass will be virtually all due to the chemical sludge, since essentially the same amount of biological degradation is occurring as in the "no-chemical" case.

IV. DISCUSSION AND RECOMMENDATIONS

The suggested calculation procedure represents the best recommendation that can be made with information currently available. It should give estimates of sludge mass which are too high and are thus conservative. It should be revised as new information becomes available.

Experiments to relate calculated values to actual sludge production should be carried out. Batch bench-top experiments should be the starting point. When possible, predictive methods and bench-top tests on which sludge production is measured should both be compared against plant operation. Plant-scale experimentation should be kept at a minimum because it is difficult and expensive to get accurate sludge mass data on a large scale.

The Blue Plains pilot plant would be an ideal place to carry our studies aimed at verifying predictive methods for determining sludge mass. The recommended scope of work for Ultimate Disposal work at Blue Plains for FY-1974 (16) includes development of bench-scale procedures for predicting sludge mass when chemicals are added to wastewater.

The literature should be surveyed and analytical measurements made as needed to determine the relation of TOC, COD and BOD to volatile solids in typical wastewaters at various stages in the treatment process.

The TOC measurement appears to be the more valuable than COD or BOD in arriving at estimates of sludge production. It would be desirable to have more information collected on TOC and soluble TOC of wastewaters. Attempts should be made to develop correlations of trickling filter and activated sludge performance which utilize TOC rather than BOD (or COD) as the primary pollutant measure.

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Table 1: Calculation of Chemical Sludge Production

Given: P_{in} = 10 mg/l

P_{out} = 1 mg/l

Al Case: dose of 19 mg/l Al
(Al/P atomic ratio = 2.18)

Fe Case: dose of 40 mg/l Fe
(Fe/P atomic ratio = 2.22)

Aluminum

Stoichiometry:

$Al + PO_4 = Al\ PO_4$

$Al + 3\ OH = Al\ (OH)_3$

9 mg/l P $\div$ 31 = 0.29 millimoles (mmol)/l $Al\ PO_4$
(M.W. = 122)

19 mg/l Al $\div$ 27 = 0.70 mmol/l Al

0.70 - 0.29 = 0.41 mmol/l Al excess (goes to $Al\ (OH)_3$)

0.29 mmol/l $Al\ PO_4$ × 122 = 35.4 mg/l $Al\ PO_4$ (MW = 78)

0.41 mmol/l $Al\ (OH)_3$ × 78 = 32.0 mg/l $Al\ (OH)_3$
67.4 mg/l

Sludge Produced:

67.4 mg chemical sludge per liter of wastewater treated

or 67.4/19 = 3.55 mg chemical sludge per mg Al

or 67.4/9 = 7.48 mg chemical sludge per mg P removed

Iron

Stoichiometry:

$Fe + PO_4 = Fe\ PO_4$

$Fe + 3\ OH = Fe\ (OH)_3$

9 mg/l P $\div$ 31 = 0.29 mmol/l $Fe\ PO_4$
(M.W. = 150.8)

40 mg/l Fe $\div$ 55.84 = 0.72 mmol/l Fe

0.72 - 0.29 = 0.43 mmol/l Fe excess (goes to $Fe(OH)_3$)
(M.W. = 106.8)

0.29 mmol/l $FePO_4$ × 150.8 = 43.7 mg/l $FePO_4$

0.43 mmol/l $Fe(OH)_3$ × 106.8 = 45.9 mg/l $Fe(OH)_2$

89.6 mg/l

Sludge Produced:

89.6 mg of chemical sludge per liter of wastewater treated

or 89.6/40 = 2.13 mg chemical sludge per mg Fe

or 89.6/9 = 9.96 mg chemical sludge per mg P removed

Sludge Production Relative to Chemical Dose - Maximum Range

	mg sludge/mg element	
	Al	Fe
atomic ratio (metal/P) ≤ 1 *	4.52	2.70
atomic ratio $\longrightarrow \infty$ **	2.89	1.92

* All of the metal goes to phosphate

** All of the metal goes to hydroxide

Table 2: Illustrative Calculation of Total Sludge Mass

Given: Plant utilizes primary clarification followed by standard rate activated sludge. Alum is to be added in a flocculation tank prior to the primary clarifier. Estimate the additional sludge produced by alum addition.

Primary clarifier of the existing plant is designed for 50% suspended solids removal (without chemical). Activated sludge plant is designed for an F/MLVSS ratio of 0.4.

Overall phosphorus removal is to be 90%. Estimate that this can be achieved at an Al/P atomic ratio of 2.0.

Influent to Primary:
P = 10 mg/l
Total BOD = 172 mg/l
Suspended Solids = 240 mg/l
Soluble TOC = 40 mg/l

A. Sludge from Primary Treatment - No Chemicals

Estimate 50% SS removal, 30% total BOD removal and 0% STOC removal.

		Sludge
240 × 0.50	=	120 mg/l

Total Sludge: 120 mg/l

B. Sludge from Primary Treatment - Al Added

Estimate 90% P removal, 85% SS removal, 65% total BOD removal and 30% STOC removal.

Al dose: $\frac{10}{31} \times 2 \times 27 = 17.4$ mg/l

$10 \times 0.90 = 9.0$ mg/l P removal

$9/31 = 0.29$ meg (milliequivalent)/l Al PO_4

$17.4/27 = 0.64$ meg/l Al

$0.64 - 0.29 = 0.35$ meg/l Al excess

$0.29 \times 122 = 35.4$ mg/l Al PO_4

$0.35 \times 78 = 27.3$ mg/l Al $(OH)_3$

62.7 mg/l

Chemical Solids: Increase by 35%, 62.7×1.35 = 84.5 mg/l

Suspended Solids: 240 × 0.85 = 204 mg/l

Dissolved Solids: 40×0.30×2.5×1.18 = 35.4 mg/l

Total Sludge: 323.9 mg/l

C. Sludge from Activated Sludge - No Chemicals

Equation 5:

$$\frac{W_v}{F} = 0.79 - \frac{0.0714}{F/M}$$

F/M is given as 0.4

$$W_v/F = 0.79 - 0.18 = \frac{0.61 \text{ lb VSS/da.}}{\text{lb BOD removed/da.}}$$

or 0.61 mg VSS/mg BOD removed

BOD in primary effluent is:

172 × 0.70 = 120 mg/l

BOD in final effluent is estimated to be ca. 12 mg/l (Figure 3-7 and Table 3-1, reference 6)

BOD removed = 120 - 12 = 108 mg/l

Therefore, 108 × 0.61 = 66 mg/l VSS produced

Assuming the sludge is 70% volatile,

66/0.70 = 94 mg/l Waste Sludge

D. Sludge from Activated Sludge - Al Added to Primary

BOD in primary effluent is:

172 × 0.35 = 60.2 mg/l

This is a very dilute waste. The existing activated sludge plant is now going to be greatly oversized. Air requirements will be greatly reduced, and the contact time may be reduced.

Keeping F/M the same (0.4),

W_v/F = 0.61 (see C. above)

Estimate BOD in final effluent to be 12 mg/l (see C. above).

BOD removed = 60.2 - 12 = 38.2 mg/l

Therefore, 38.2 × 0.61 = 23.3 mg/l VSS produced

Assuming sludge is 70% volatile,

23.3/0.70 = 33.3 mg/l waste sludge

E. Comparison of Sludge Quantities

	Sludge Quantities (mg/l)	
	No Chemical	Al Added
Primary Clarifier		
sludge from SS	120	204
sludge from dissolved solids	0	35.4
chemical sludge	0	84.5
total clarifier sludge	120	323.9
Secondary Clarifier		
waste activated sludge	94	33.3
Total Sludge	214	357.2
total sludge excepting chemical sludge	214	272.7

APPENDIX D

Estimation of Lime Dose and Sludge Production in Tertiary Treatment with Lime*

SUMMARY

A quantitative calculation procedure for estimating the required lime dose and the quantity of sludge produced in tertiary treatment of wastewater with lime is presented. Development and verification of a bench-scale procedure for obtaining this information is recommended.

PROCESS DESCRIPTION

In the usual understanding of the term, tertiary lime treatment is lime treatment of wastewater which has already been partially renovated by conventional primary settling followed by biological treatment. Other processing schemes which combine primary settling and biological processing in a single step can produce an effluent similar in quality to conventional primary settling followed by biological treatment. If lime treatment follows such a process, it should be classified as a tertiary lime treatment.

The objective of tertiary lime treatment is to further upgrade the renovated wastewater. Often the primary purpose is to remove phosphate. Since pH is elevated, it is often possible to remove ammonia by stripping the effluent with air. When very complete renovation is desired, the effluent may be treated with activated carbon and filtered, usually after pH adjustment.

The extent of phosphate removal is a function of a number of variables including the chemical composition of the wastewater and the nature of the phosphate compounds contained. The most important variable controlling phosphate removal and quality of effluent is pH rather than quantity of lime added. Figure 1, which is taken from Siden and Patel(1), shows a correlation of P-removal as a function of pH, utilizing data from several sources.

Another factor of importance is the hardness level of the wastewater. O'Farrell, Bishop et al.(2) have found it necessary to go to pH in excess of 11 to get good clarification with the low hardness water at Blue Plains. Berg, et al.(3) obtained satisfactory clarification at pH of about 10 in the hard water at Lebanon, Ohio.

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* Information was presented previously in a NERC-Cincinnati Memorandum, J. B. Farrell to Record, April 25, 1973.

Phosphate precipitation may be adequate but clarity of final effluent may be insufficient at pH's near 10. When phosphate removal is adequate for their purposes but clarity is inadequate, several investigators have utilized ferrous or ferric salts as coagulants rather than increasing the pH by addition of more lime.

LIME CONSUMED

The amount of lime consumed is considered in this presentation because the sludge production is related to the lime dose.

The chemistry of lime-softening of natural waters is sufficiently well developed so that the charge of lime required to achieve a given removal of calcium and magnesium can be predicted and the final pH can be closely estimated. With wastewaters, many authors warn that the suspended and dissolved organic materials as well as ortho and polyphosphates apparently affect lime dosage required and can cause supersaturation of precipitating species. Typically, lime dose required to reach a given pH is higher than predicted from softening equations. Likewise, calcium and magnesium content of the product water is higher than would be predicted for lime treated natural waters.

A correlation for estimating the lime dose needed to bring a secondary effluent to a given pH has been developed by the writer from experimental results of several investigators (2,3,4,5,6) and is presented in Figure 2. The pH is seen to be reasonably well correlated with the ratio of lime dose to initial alkalinity. Other factors which doubtlessly affect the result are the ratio of magnesium to calcium in the wastewater, the ionic strength, and the phosphate level. The effects caused by these variables can be considered by well known methods, and computer programs have been developed to make the necessary calculation (1,7). However, the accuracy of these calculations is uncertain because of the uncertain effects of contaminants in wastewater.

The correlation in Figure 2 can be utilized to predict lime dose if an estimate of the desired pH level can be made. The curve is entered at the ordinate, and the abscissa, the ratio of CaO dose to alkalinity, is read from the graph. If the alkalinity of the water is known, active CaO dose can be calculated. Total quicklime dose can be calculated from active CaO dose and the active CaO content of the quicklime.

SLUDGE PRODUCTION

The three principal reactions which occur when wastewater is treated with lime are as follows:

$$5Ca(OH)_2 + 3HPO_4^{--} \text{ ——— } Ca_5OH(PO_4)_3 + 6OH^- + 3H_2O \qquad (1)$$

$$Mg^{++} + 2OH^- \text{ ——— } Mg(OH)_2 \qquad (2)$$

$$Ca(OH)_2 + HCO_3^- \text{ ——— } CaCO_3 + H_2O + OH^- \qquad (3)$$

The amount of sludge produced by lime treatment of secondary effluent can be estimated by applying the stoichiometry of these equations. The procedure for carrying out the calculation is explained in detail below.

The calculation of sludge quantity is intimately related to lime dose. Lime dose is related to alkalinity of the water and the desired pH level. The best way to determine lime dose and pH level is to run jar tests on the wastewater in question and determine the pH level which gives the desired phosphate removal and wastewater quality improvement. If jar tests cannot be carried out, then judgements of pH level must be made on the basis of past experience. The publications of Bishop et al. (2) and Berg et al. (3) are useful in this regard. For example, Bishop et al. found that a pH of ca. 11.0 was needed to get 90 percent phosphate removal with the District of Columbia's soft water, whereas with hard water at Lebanon, Ohio, Berg et al. achieved 90 percent removal with pH of ca. 10.0.

If pH desired can be established, and alkalinity is known, lime dose can be estimated from Figure 2. Sufficient information is now available to commence the calculation.

The information required and the steps to take in estimating the sludge production are listed below and are illustrated with a specific example in Table 1. Informational input needs are marked with an asterik.

Information Needed	Determination
A. P_{in}^*, desired P removal* (Sometimes, BOD_{in}, desired BOD removal), Results of jar test or experience*	pH level
B. Alkalinity of wastewater*, pH level, Figure 2	CaO dose
C. P_{in}, P removal, Equation 1	$Ca_5OH\ (PO_4)_3$(abbrev.: HAP) precipitated
D. Mg_{in}, from analysis or estimate*, Mg_{out}, from analysis or Figure 4, Equation 2	$Mg(OH)_2$ precipitated
E. Ca_{in}, from analysis or estimate*, Ca_{out}, from analysis or Figure 3, Ca from lime dose (see item B), Ca removal in HAP (see item C), Equation 3	$CaCO_3$ precipitated
F. pH (see item A)	Verify that sufficient CO_3^{--} is present. If not, estimates of Ca_{out} was in error.
G. Active CaO in lime*	Inerts brought in with quicklime.

The procedures for steps A and B have already been presented. Step C requires no explanation. If estimates of Mg_{out} and Ca_{out} are needed for steps D and E, the data of Berg *et al*.(3) are useful. Figures 3 and 4 show the calcium and magnesium levels obtained at the clarifier outlet in Berg *et al*.'s long-term evaluation of tertiary lime treatment of secondary effluent at Lebanon, Ohio. Magnesium (Figure 4) precipitation commences at pH 10 and is essentially complete at pH 11. The percent in solution could be estimated as declining from 100% at pH 10 to 0 at pH 11.

The calcium concentration (Figure 3) is seen to decline precipitously when pH is increased to 9.5. Concentration then increases as pH is increased further. This behavior is readily explained qualitatively from our knowledge of bicarbonate-carbonate equilibria. When pH is increased, bicarbonate ion is converted to carbonate ion. When the solubility product of $CaCO_3$ is exceeded, precipitation occurs and Ca concentration falls. As pH is increased further by more $Ca(OH)_2$ addition, eventually all of the CO_3 is removed by $CaCO_3$ precipitation. Calcium concentration then increases as calcium hydroxide dissolves to the limit of its solubility.

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* Informational input is needed.

Step E outlines the calculation of calcium carbonate precipitation. The calcium carbonate deposited is calculated from a calcium balance. After considering the amount of calcium removed in the hydroxyapatite $(Ca_5OH\ (PO_2)_3)$, the $CaCO_3$ is calculated from the net loss of calcium.

A verification step is advisable to determine whether there is sufficient bicarbonate to account for the $CaCO_3$ produced. Bicarbonate can be determined from the alkalinity. At pH below about 8.3, all of the alkalinity measured is due to bicarbonate.* If the bicarbonate is insufficient to "match up" with the lost calcium as calculated from the material balance, the calcium in the final effluent was estimated at too low a value. There is not much chance of this error occurring at pH levels below about 10.8.

The entire procedure described, including the verification step and the totaling of all of the components of the sludge, is shown in the illustration in Table 1. It is evident from the total quantities listed at the end of the table that calcium carbonate makes up about three-quarters of the mass of the sludge. For this reason, substantial errors could occur in the estimates of the other sludge quantities without introducing much error into the final result.

Suhr (8) has stated that it is difficult to obtain an accurate gravimetric measurement of sludge quantities in a laboratory test due to loss of solids during decanting, etc. As an alternative, he suggests estimation of the quantities of sludge from the chemistry involved and water analyses before and after jar tests (in his suggested procedure, lime dose is known, and calcium carbonate sludge is calculated from a calcium balance). It is this writer's opinion that if the wastewater which will be treated is actually available, there should be no better way to estimate lime dose and sludge quantity than by actual test. Experimental development and verification of a satisfactory bench-scale test for predicting lime dose and sludge quantity is urgently needed.

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*At pH below 7, there is more potential carbonate available due to the presence of dissolved carbon dioxide, which is not measured in the alkalinity test. Estimates of dissolved CO_2 can be made by following procedures outlined in "Standard Methods" (9).

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9. "Standard Methods for the Examination of Water and Wastewater," 13th edition, published by APHA, AWWA, WPCF, Washington, D.C., (1971).

TABLE 1

Illustration of Procedure for Estimating Sludge Quantity

Secondary Effluent Characteristics

Phosphate Content	10 mg/l as P
Alkalinity	300 mg/l as $CaCO_3$
Calcium	100 mg/l
Magnesium	20 mg/l

Treatment Conditions

Remove 85% of phosphate by raising pH to 10.5

Final Phosphate Content	1.5 mg/l as P
Estimate of Ca (Figure 3)	50 mg/l
Estimate of Mg (Figure 4)	10 mg/l

Lime Dose

From Figure 1, 0.92 mg CaO/mg alkalinity at pH 10.5.

$$\text{dose} = 0.92 \times 300 = 276 \text{ mg/l CaO}$$

Assume quicklime is 90% active CaO

$$\text{Total quicklime} = \frac{276}{0.90} = 307 \text{ mg/l}$$

Inerts with quicklime = 30.7 mg/l

Sludge from Phosphate

$$(10 - 1.5)\left(\frac{502}{93}\right) = 45.8 \text{ mg/l } Ca_5(OH)(PO_4)_3$$

$Mg(OH)_2$ in Sludge

$$(20 - 10)\left(\frac{58.3}{24.3}\right) = 24.0 \text{ mg/l } Mg(OH)_2$$

Sludge from $CaCO_3$ Precipitation

$$\text{Input Ca} = 100 + 276 \times \frac{40}{56}$$

(sec.effluent) (from lime dose)

$$\text{Output Ca} = 45.8 \times \frac{5 \times 40}{502} + 50 + Y$$

(removed with hydroxyapatite) (remaining in solution) precipitated as $CaCO_3$

$$Y = 100 + 197 - 18.3 - 50 = 129 \text{ mg/l}$$

$$129 \times \frac{100}{40} = 323 \text{ mg/l } CaCO_3 \text{ precipitated}$$

TABLE 1 (continued)

Procedure for Estimating Sludge Quantity

Total Sludge

Inerts in quicklime	30.7
$Ca_5OH(PO_4)_3$	45.8
$Mg(OH)_2$	24.0
$CaCO_3$	323.0
	433.5 mg/l

Verification that Sufficient CO_3 is Present

300 mg/l alkalinity (as $CaCO_3$)

$300 \times \frac{1}{50} = 6.0$ g-equivalents (or g-mols) HCO_3^-

$$HCO_3^- + Ca^{++} + OH^- \longrightarrow CaCO_3 + H_2O$$

6.0 g-mols HCO_3^- can produce 6.0 g-mols $CaCO_3$

$6.0 \times 100 = 600$ mg/l $CaCO_3$

The CO_3 available could produce as much as 600 mg/l $CaCO_3$. This is substantially greater than the amount calculated above (323 mg/l) from the calcium balance. It is evident that there is ample CO_3 present. If there were insufficient CO_3 (which can happen at pH of 11 and greater), it would indicate that the estimate of Ca^{++} after treatment was too low. The amount of $CaCO_3$ indicated by the calculation from the alkalinity would be correct.

Additional Sludge from Recarbonation

Recarbonation to pH 9.5 will reduce Ca concentration to about 30 mg/l (see Figure 3). For this example, the additional calcium carbonate sludge produced is calculated as follows:

$(50 - 30)\left(\frac{100}{40}\right) = \underline{50 \text{ mg/l } CaCO_3}$

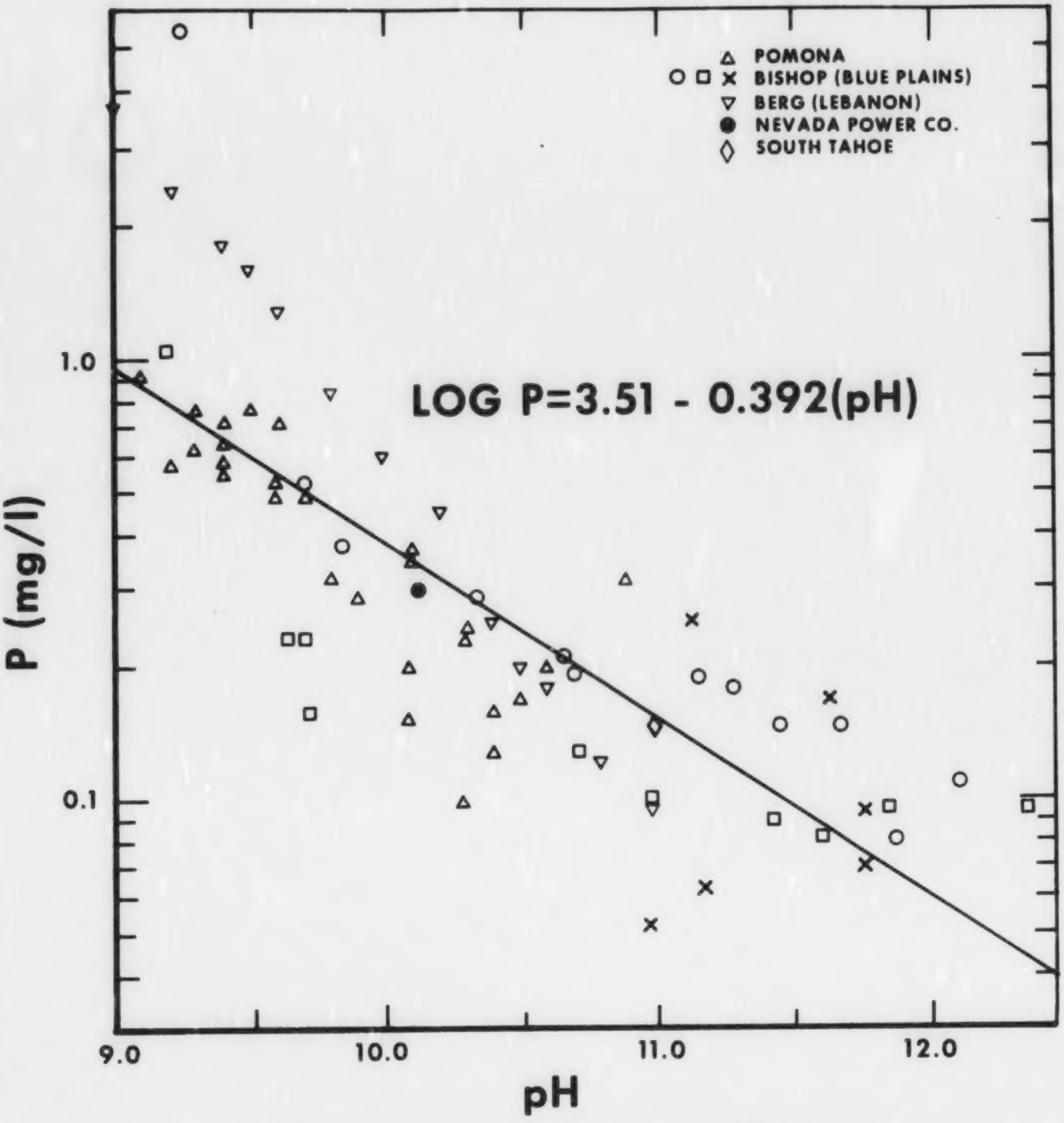

FIGURE 1: EFFECT OF pH ON TOTAL P
(FROM SEIDEN AND PATEL)

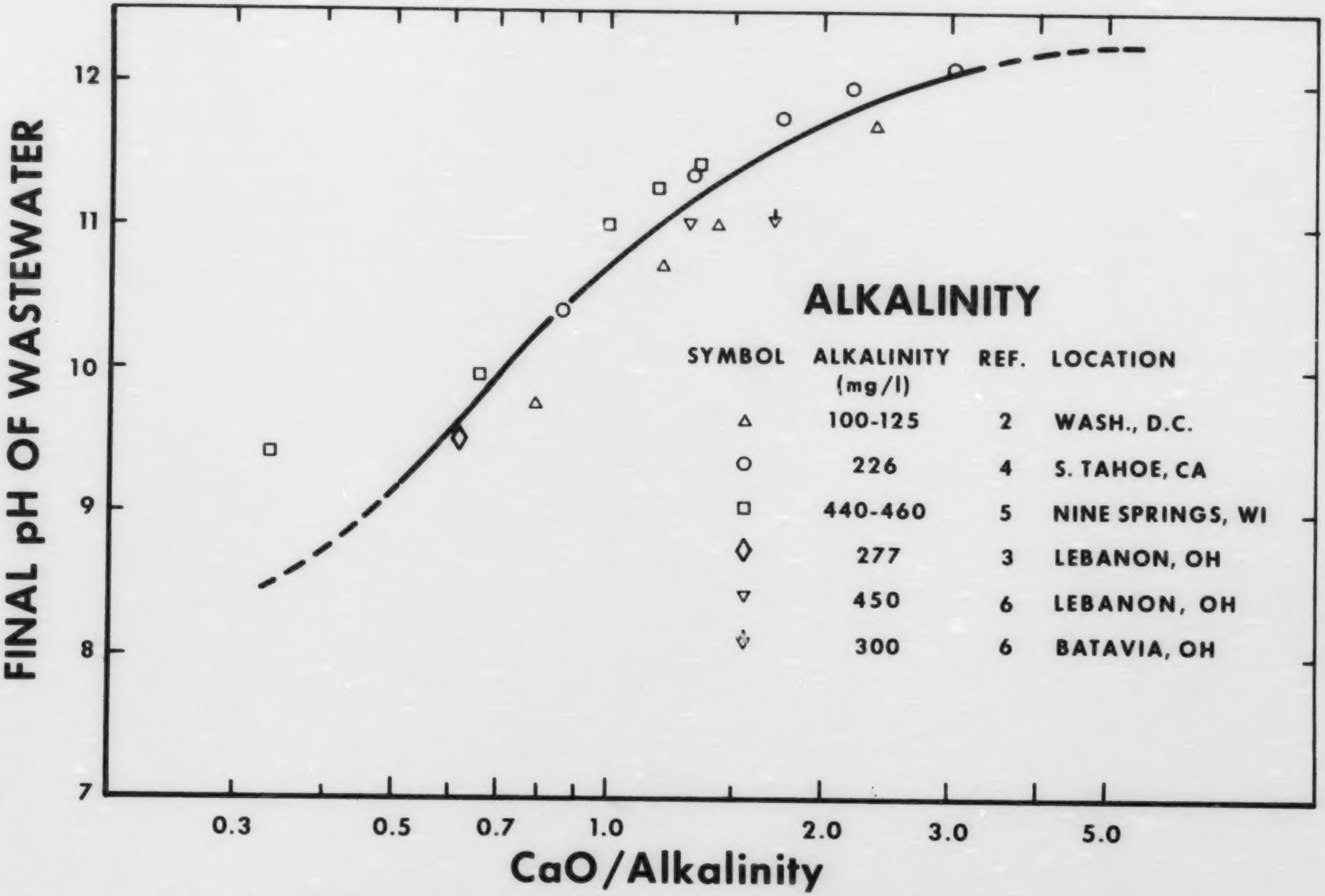

FIG. 2: RATIO OF LIME DOSE (mg/l) TO INITIAL WASTEWATER ALKALINITY (mg/l)

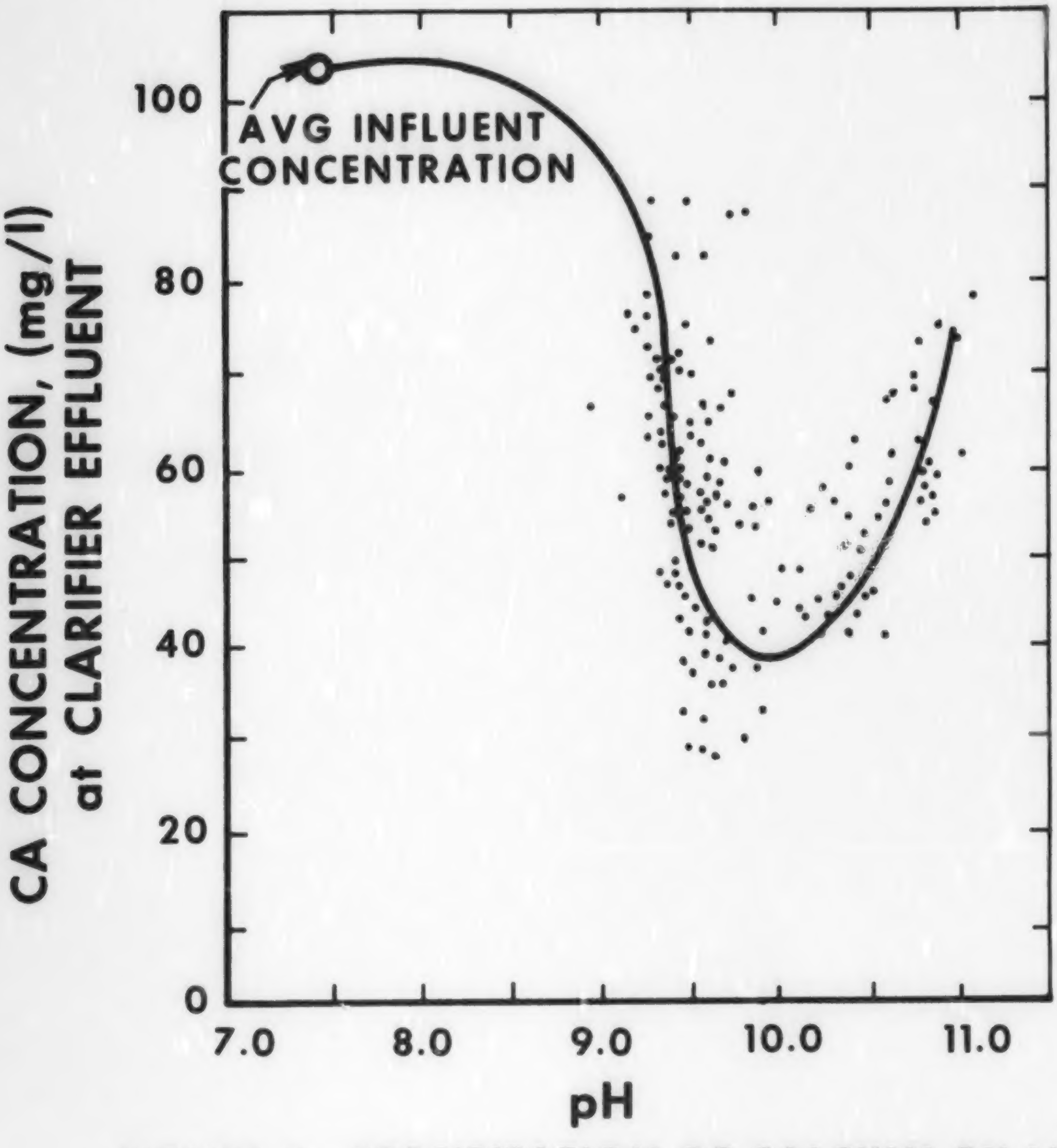

FIGURE 3: PRECIPITATION OF CALCIUM BY LIME ADDITION (AFTER BERG et al)

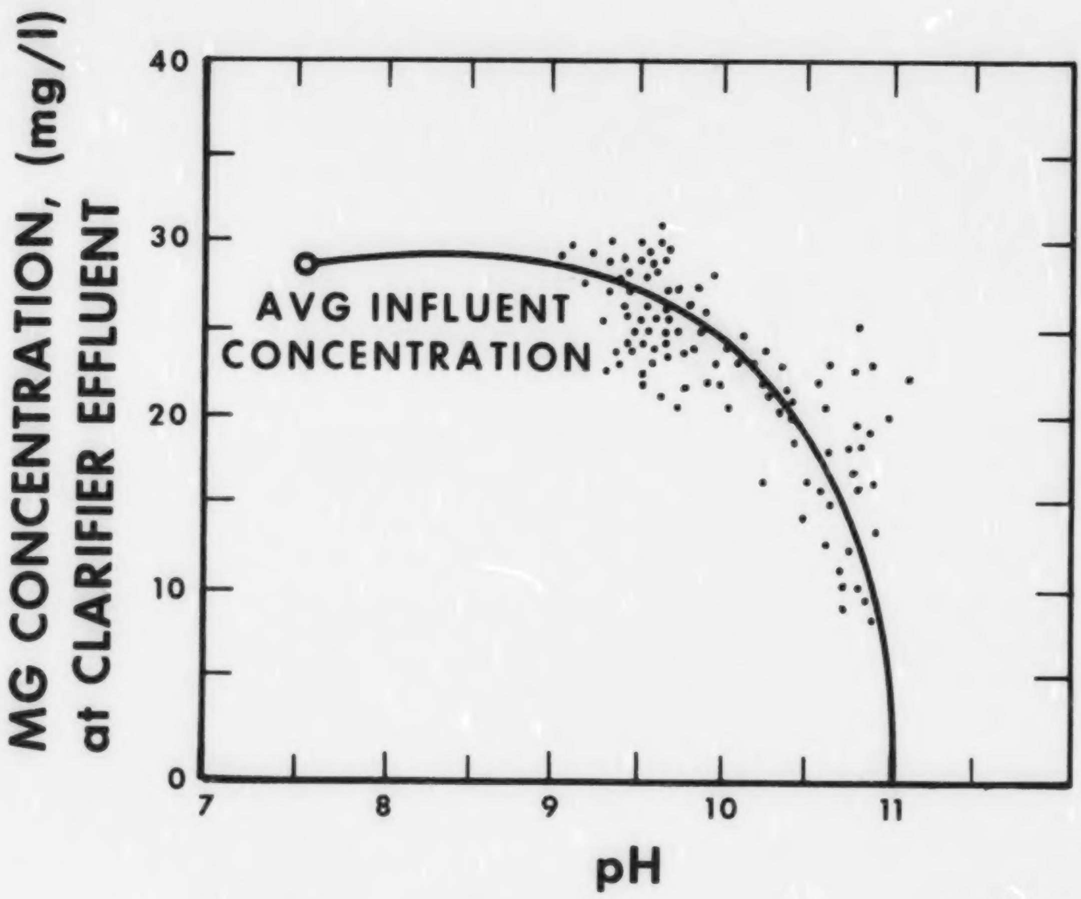

FIGURE 4: PRECIPITATION OF MAGNESIUM BY LIME ADDITION (AFTER BERG et al.)

APPENDIX E

SLUDGE INFORMATION SUMMARY NO. 5

EIMCO'S SALT LAKE CITY PILOT PLANT

TYPE OF SLUDGE

Primary physical-chemical treatment sludges, produced by addition of the following chemicals to the raw sewage in an Eimco reactor-clarifier:

(a) ferric chloride
(b) alum
(c) calcium hydroxide (herein called lime).

SOURCE OF INFORMATION

Draft final report: "Physical-Chemical Treatment of a Municipal Wastewater Using Powdered Carbon" (to be published by EPA Office of Research and Monitoring, Project #17020 EFP, draft report is dated May, 1972).

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DATE PREPARED August 25, 1972. 30 pp.

OBJECTIVE OF SUMMARY

This and similar summaries extract information on sludges from reports of investigations on wastewater treatment. Such reports are often lengthy, and their primary objectives are unrelated to sludge disposal. The "Sludge Information Summary" condenses the information on sludges into a few pages. Where possible, results are related to other studies, and judgements are made by the summary author regarding the value of the results. Unless otherwise noted, however, the data and observations of the report author have been accepted at face value and are merely recorded in the summary.

In many cases in this summary, the authors' text has not been condensed but is used verbatim. These cases are identified by quotation marks. Except when noted by an "S" following the number, tables and figures are the authors.

INTRODUCTION

Municipal wastewater at Salt Lake City was treated in a nominal 100 gpm pilot plant by chemical coagulation-precipitation, powdered activated carbon adsorption, and granular media filtration. Spent carbon was gravity thickened, dewatered by vacuum filtration, and thermally regenerated in a fluidized bed furnace. Solids-contact units were used to effect chemical treatment and carbon contacting.

Addition of ferric chloride or alum or pH adjustment by lime addition effectively produced coagulation and phosphorus insolubilization. Based on total treatment costs, included sludge disposal, the authors conclude that alum treatment is the economic choice for Salt Lake City municipal wastewater.*

EXPERIMENTAL RESULTS

A. Bench-Scale Data

No information on sludge production is presented for alum and ferric chloride addition. One example of solids production resulting from lime treatment is given in the authors' Figure 8. The authors state, "Solids production in the pH range of 9.5 to 10.5 is mainly due to precipitation of $CaCO_3$. In the pH range 10.5 to 11.5 few additional solids are produced, presumably only small quantities of $Mg(OH)_2$ (see circles in Figure 8). Solids production in this range is about 7000 lb/MG (840 mg/l). Above a pH of about 11.5 solids production can only be explained as due to unreacted $Ca(OH)_2$."

Solids production in pounds total sludge per pound of lime added is presented on Figure 8 (see the triangles). This writer has added data (see the squares) from the reactor-clarifier (from Table 10) to this figure. Agreement is very poor despite the fact that alkalinity is about the same.

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* In this writer's opinion, this conclusion should be qualified, because lime process costs appear excessive, and Al and Fe sludge data are scant.

B. Pilot Plant Description

"The pilot plant influent was coarse screened and comminuted Salt Lake City raw wastewater. About 350 gpm was diverted from the main Salt Lake City pump station discharge header to the pilot plant raw wastewater sump." A portion of this stream was fed to the pilot plant; the remainder overflowed and returned by gravity to the pump station. Plant flow was automatically controlled at any desired constant flow rate equal to or less than 150 gpm.

"Chemical treatment and clarification of raw wastewater was accomplished in a 12 foot diameter Eimco Reactor-Clarifier solids-contact treatment unit, manufactured by Eimco Processing Machinery Division, Envirotech Corporation, Salt Lake City, Utah.

Figure 15 shows a schematic of this unit. Raw wastewater entered the unit via the influent pipe A to a draft tube E. Inorganic coagulants were added to the raw wastewater at B. Lime was added at point C. A slow speed turbine F, pumped raw wastewater, chemicals, previously formed chemical precipitates and wastewater solids up the draft tube and into the reaction zone. The pumping turbine capacity was estimated to be about 5-8 times the average hydraulic throughput. Polyelectrolyte flocculation aids were introduced into the reaction zone at point D. Reaction zone slurry flowed under the reaction zone cone Q, into an increasing area upflow clarification zone and were either drawn up the draft tube or removed through thickening cone I.

Partially thickened sludge was automatically removed from the treatment unit by gravity flow through line R and a timer controlled sludge valve S. An automatic water backflush of line R was provided at valve T. Chemical sludge blowdown was routed to a 2000 gallons (8 foot diameter) holding tank which was equipped with a turbine mixer.

Since the chemical treatment unit received raw wastewater, provision was made for clarification zone surface skimming by mechanism K. Floatable materials were kept from passing over the peripheral effluent launder M (a V-notched weir) by baffle L. Effluent neutralization was accomplished by addition of concentrated sulfuric acid to the effluent launder at point N. Clarified effluent exited the unit at splitter box W which divided flow to one or two carbon contactors, or to waste. A sample of clarifier effluent was continuously withdrawn at point V and conveyed to a composite sampling and process turbidity monitoring system."

C. Ferric Chloride

Summarized results with ferric chloride are presented in Table 2S. Dosage of ferric chloride was held constant with respect to flow rate and was not varied with P-content of the influent. Removals of phosphorus and suspended solids were adequate. The authors speculate that the high ferric in the effluent is due to reduction of ferric to ferrous in the reactor. See the full report for discussion of effluent quality.

Sludge Quantity - Sludge quantities have been calculated by measuring the total sludge production and subtracting out the difference between inlet and outlet suspended solids. This writer has calculated the chemical sludge production assuming that all phosphate becomes $FePO_4$ and excess ferric ends up as $Fe(OH)_3$. Ferric ion lost in the effluent (see Table 2S) is subtracted from the dose (ferric in effluent for Run F-2 was estimated at 6.0 mg/l). Calculated and measured data are presented below:

Chemical Sludge Quantity	F-2	F-3	F-4
Calculated (lb/lb Fe)	1.81	1.68	1.75
Measured (lb/lb Fe)	2.22	1.78	2.38
Ratio: meas./calc.	1.23	1.06	1.36

Measured sludge quantities are higher than calculated values by an average of 22 percent. Part or all of the discrepancy is due to the fact that the measured chemical sludge includes colloidal solids brought down by the ferric hydroxide floc.

Thickening - Laboratory thickening tests were conducted on three 24-hour composite samples of sludge collected from the reactor discharge in Runs F-3 and 4. Results are summarized below:

Test	1	2	3
Initial Solids (%)	0.40	0.78	0.98
Solids after 24 hrs. settling (%)	3.9	2.8	3.9

The calculated thickening rate curve is presented in Figure 24.

The authors observed that a weighted average of clarifier underflow solids concentration was 1.5% solids. From Figure 24, thickening rate for

1.5% solids sludge was estimated at 12 lb/da.ft^2 at a thickener underflow concentration of 4.5%.

Filtration - "Vacuum filtration leaf tests were conducted on three partially thickened 24-hour composite sludge samples of chemical clarifier underflow. The results of these tests, summarized in Table 4, indicate that sludges of from 1.6 to 3.3 percent concentration were dewatered 80-85 percent moisture at predicted full scale filter yields of about 0.3 pound of dry solids per hour per square foot of filter area. These filter yields were predicted for a 3/16 inch filter cake thickness which was only marginally dischargeable. Conditioning of the dilute ferric-sewage sludge with 24 percent lime on a dry solids basis resulted in a dischargeable 3/16 inch filter cake and a filter yield of 1 lb/hr.ft^2."

The authors state their belief that the results of the thickening and dewatering tests are conservative. They recommend additional studies to achieve more reliable design data.

D. Alum

Summarized results with alum are presented in Table 5S. Alum dosage was held constant with respect to flow rate and not varied with P-content of the influent. Removal of phosphorus and suspended solids was adequate. Data indicate some removal of soluble TOC. See the full report for discussions of effluent quality.

Sludge Quantities - Chemical sludge quantities have been calculated by measuring the total sludge production and subtracting out the difference between inlet and outlet suspended solids. This writer has calculated the chemical sludge production assuming that all the phosphate becomes $AlPO_4$ and excess phosphate ends up as $Al(OH)_3$. From the data presented on soluble organic carbon removal, this writer has calculated the mass associated with this soluble carbon (assuming mass = 2.5xSTOC) and subtracted this quantity as well as the suspended solids removed from the total sludge production. These two "measured" sludge quantities are compared to the measured values in the following table:

	A-1	A-2
Chemical Sludge Quantity (lb/lb Al)		
Measured (Total-SS)	4.2	5.7
Measured (Total-SS-STOC)	3.2	3.5
Calculated	3.3	3.4
Ratio: Meas.(Total-SS)/Calc.	1.3	1.7
Ratio: Meas.(Total-SS-STOC)/Calc.	1.0	1.0

The measured sludge production when only suspended solids removal is subtracted from the total sludge production is 1.3 to 1.7 times higher than the calculated sludge production. When the mass associated with soluble TOC removal is subtracted out, the agreement between measured and calculated values is excellent.

Thickening - Laboratory thickening tests were conducted on 24-hour composite samples of sludge collected in Run A-1. Condensed results are presented below:

Test	1	2
Initial Solids (%)	0.36	3.3
Solids after 24-hr settling (%)	0.26	1.8

The authors calculated that a thickener loading of less than 6 lb/da.ft^2 is indicated if a 1.5% solids sludge is to be produced from a feed of 0.36% solids.

Filtration - Vacuum filtration leaf test data are presented in Table 8. The alum sludges would not produce a removable cake without conditioning. Filter yields with the chemical conditioners utilized were low and chemical requirements high. The authors state that more work on alum sludge filtration is needed.

E. Lime

Summarized results with lime are presented in Table 9S. Operation was controlled by adjusting the lime dose to maintain a constant pH (± 0.2). Lime dosage was apparently reasonably constant. Average lime feed rate for a run was computed using the total volumetric flow of wastewater through the unit and the total number of bags of lime used. Phosphorus and suspended solids removals were adequate. For discussion of phases of the study not related to sludges, see the original report.

Sludge Quantities - Chemical sludge quantities were determined by measuring the total sludge production and subtracting out the difference between inlet and outlet suspended solids. The authors have plotted chemical sludge production against pH in Figure 32. For the two runs above pH 11.4, the amount of dissolved calcium in the effluent was very large and would probably have to be reduced by carbonation. This would increase the sludge production considerably for these points.

This writer has plotted data from the authors' Figure 8 on Figure 32. These data were obtained in batch tests on a beaker scale. The difference in slope is substantial. The beaker-scale data are for total sludge production rather than chemical sludge. If suspended solids were subtracted out, it would drop the curve slightly and make it closer to the horizontal, exaggerating the large difference in slope. The much more extensive data collected in the reactor are probably reliable. The difference may be due to errors in the batch test or to basic differences between batch tests and continuous flow tests in a solids-contact reactor.

This writer has presented the sludge production data in a different fashion in Figure 32S. Lime dosage is plotted against measured chemical sludge production and against calculated sludge production. The latter quantity is calculated by summing the masses formed of hydroxyapatite, $CaCO_3$ (as indicated by net loss of CO_2 and HCO_3 between influent and effluent), and $Mg(OH)_2$. Details of the calculation are presented in Table 10S. There was generally a net disappearance of Ca^{++}. This was considered to be either undissolved lime or lime which reacted and was removed with the organic solids. It was added into the calculated sludge quantity as $Ca(OH)_2$. For Runs 3 to 9, the average Ca^{++} disappearance was 50 mg/l (as $Ca(OH)_2$), or about 10% of the lime fed. Runs 10 and 11 were excluded. Run 11 was at an extremely high addition level. Run 10 was also at a high dose level, and dose and pH level were given by the authors as approximate.

The calculated sludge quantity is really an experimental value which is determined indirectly. It is expected to show some error because of interferences of sewage components in the analytical measurements, but if the water analysis does not change greatly, it should correlate well with lime dosage. As Figure 32S indicates, it does in fact give a good correlation with lime dosage. It is expected that this curve would reach a plateau (see circles in Figure 8) simply because there are no more materials in solution which can precipitate.

The good correlation of the calculated sludge quantity with lime dosage leads to the expectation that measured sludge quantity should also correlate well with dosage. It does not. This writer concludes that this is experimental scatter, and a line has been drawn which represents the measured data reasonably well. Run 3 (1100 mg/l of sludge at 425 mg/l lime dose) appears to be in error and should be discarded.

The "measured" curve is approximately 20 percent higher than the "calculated" curve. The measured curve should be used to predict sludge quantity for waters similar to Salt Lake City wastewater. From the desired pH level, lime dosage and sludge production can be estimated. Fortuitously, the measured sludge quantity versus lime dosage is a direct proportion. Measured sludge quantity then is equal to 1.6 times the lime dosage in the pH range 10.7 to 11.0.

This method of predicting sludge quantity will give different results from the authors' Figure 32.

Thickening - "Figure 33 shows the results of laboratory thickening tests. Each curve represents one sludge sample and shows the thickener loading (i.e., no scale-up factor) related to various thickened sludge concentrations. The data is somewhat erratic, reflecting variable sludge characteristics experienced over the eight month period during which the tests were conducted. It is apparent from the feed solids data in Figure 33 that the moderate treatment pH sludges tested were generally more concentrated than the high treatment pH sludges.

The lower-right extremity of the curves in Figure 33 represents the sludge thickness attained after 24-hours of gravity thickening and is defined as the maximum possible or ultimate concentration. A plot of maximum thickened concentration versus initial or feed solids concentration is presented in Figure 34. It appears that the more concentrated the chemical clarifier underflow (initial solids) the more the solids can be concentrated.

To more readily enable use of the thickening data in Figure 33, an operating line is drawn through the set of curves. For the data presented, high and moderate treatment pH sludges are separately considered.

Generally, higher vacuum filter yields and drier filter cakes are obtained with higher feed solids concentration (i.e., thickener underflow solids concentration). Since vacuum dewatering costs are considerably higher than gravity thickening costs, the operating lines in Figure 33 are drawn at reasonably high underflow solids concentration values. If the thickener solids loading and underflow concentration at the intersection of each thickening curve with the operating line is plotted versus thickener feed solids, a suggested design curve can be drawn.

Figure 35 presents such a plot for suggested design and thickening results for the high and moderate treatment pH sludges. A scale-up factor of 0.80 was applied to the observed thickener solids loading values taken from Figure 33."

"The effect of polyelectrolyte flocculation aid on thickening results is indicated in Figure 36 for a sample of high treatment pH sludge. The data shows that the lower the feed solids concentration, the greater the percentage increase in thickener solids loading possible. The cost of polyelectrolyte probably cannot be justified on the basis of reduced thickener size. Polyelectrolyte use on a part time basis may be justified. For example, consider an installation designed for thickening 6 percent feed solids to 12 percent, at 21 lbs/day-ft^2 without polyelectrolyte. If for some operational reason, the feed solids dropped to 3 percent the thickener would still produce 12 percent underflow if about 0.04 lbs polyelectrolyte per lb dry sludge solids were added."

Filtration - "Numerous vacuum filter leaf tests were conducted on both high and moderate treatment pH sludges. A synthetic filter media, Polypropylene-852F, was found to result in good filtrate clarity of less than 200-300 mg/l suspended solids and would discharge the cake easily. The filter leaf test results are presented in Figure 37. Maximum predicted vacuum filter yields for the operating conditions indicated are shown. The 33 percent drum submergence and 20 inches of Hg vacuum level are acceptable design values. The results in Figure 37 indicate that treatment pH and feed solids significantly affect the vacuum filter yield. The linear regression lines shown have correlation coefficients of 0.90

and 0.96 for high and moderate treatment pH values respectively.

Several tests were conducted with anionic polyelectrolyte flocculation aid (Dow Chemical Co., AP-30) at dosages ranging from 0.2 to 0.6 lb/100 lb dry solids. Vacuum filter yields were found to increase from 30 to 70 percent above those shown in Figure 37 for several feed solids concentrations."

See the section below for data on moisture content of filter cake.

Sample Problem - "The utility of the lime-sewage sludge thickening and dewatering data presented can best be illustrated by the following example which indicates suggested design criteria and results for lime-sewage sludge produced in this study. Table 11 is a summary of the following example:

Chemical clarifier underflow is taken as the weighted average of all such data presented in Table 9. From Figure 35, thickener solids loading and underflow concentration is determined. For the observed thickener underflow concentration (vacuum filter feed solids) a filter yield is determined from Figure 37. For the vacuum filter operating conditions specified in Figure 37, the following relationships would exist:

$$CT = \frac{FT}{0.33} \qquad (2)$$

$$\theta_D = 0.50\ CT \qquad (3)$$

$$W = \text{Yield} \times \frac{CT}{60} \qquad (4)$$

Where: CT = drum cycle time, min
FT = cake form time, min
θ_D = cake dry time, min
W = cake weight, lbs/ft^2
Yield = full scale filtration rate, lbs/hr-ft^2

Figure 38 presents the correlation determined between filter cake moisture content and modified correlating factor (θ_D/W) for the treatment pH and filter feed solids conditions indicated. Determination of filter cake moisture content presented in Table 11 was as follows (example is for moderate treatment pH)

1. $CT = \frac{0.6}{0.33} = 1.8$ min

2. $O_D = (0.5)(1.8) = 0.9$ min

$$W = \frac{(12.8)(1.8)}{60} = 0.38 \text{ lbs/ft}^2$$

3. $(0.8)\frac{O_D}{W} = \frac{(0.9)(0.8)}{0.38} = 1.9 \text{ min-ft}^2\text{/lb}$

From Figure 38, a moisture content of 67 percent is observed at $O_D/W = 1.9$."

The method described above requires reference to leaf test data to obtain form time. In this writer's opinion, this step is not necessary. In fact, since fractional immersion time (0.33) and fractional drying time (0.50) are known, both yield and the correlating factor are then functions of W/CT alone. Moisture content thus can be obtained without the need to establish form time. If form time is desired, the following procedure is suggested:

a) Calculate wet loading, based on 0.1875-inch wet cake thickness and density of ca. 1.2 g/cm^3.

b) Calculate dry loading based on an approximate moisture content estimated from Figure 38 (or use an accurate value determined by using yield to calculate the correlating factor).

c) With dry loading and yield known, cycle time, dry time, and form time can be determined. Moisture content can be determined accurately from Figure 38.

COMMENTS

Determination of sludge data was a secondary objective of the authors' investigation. Nevertheless their data are of unique value because the sludges were produced by addition to the primary of the three most important chemicals used in physical-chemical treatment, utilizing the same source of sewage and the same equipment train. The authors' investigation is continuing and more information will be obtained.

The alum and ferric sludges show low solids content on thickening and poor filtering characteristics when compared with lime. This is expected but may have been exaggerated by the fact that the primary clarifier was a solid-contact reactor. The internal recirculation in this type of reactor may have a deleterious effect on the dewaterability of ferric and alum sludges.

TABLE 2 S

Condensation of Tables 2 and 3, $FeCl_3$ Treatment

Run Number	F-2	F-3	F-4
Duration (day)	37	13	4
$FeCl_3$ (mg/l of Fe)	41	50	40
Polymer Type	Atlasep 2A2	Atlasep 2A2	-
Polymer dose (mg/l)	1.0	1.5	0
Reaction Zone Solids (g/l)	2.9	3.3	1.2
Blowdown Volume, % of flow	0.9	1.3	2.0
Blowdown concn. (g/l)	17	13	10
Suspended Solids, In (mg/l)	75	94	138
Out (mg/l)	12	14	33
Total P, In (mg/l)	6.0	7.8	7.3
Out (mg/l)	0.9	0.2	0.5
Ferric, In (mg/l)		1.2	1.9
Out (mg/l)		6.2	8.5
Total Sludge, lb/MG Influent	1280	1410	1670
Total Sludge, mg/l Influent	154	169	200
Chemical Sludge, mg/l Influent	91	89	95
lb chemical solids/lb Fe fed	2.2	1.8	2.4

TABLE 4: $FeCl_3$ TREATMENT: VACUUM FILTRATION LEAF TEST RESULTS

Test	Feed Solids % by Weight	Cycle Time Minutes	Full Scale Filtration Yield[a] lbs/hr-ft^2	Cake Moisture % by Weight
1	2.5	16	0.37	85
2	3.3	20	0.32	83
3	1.6	25	0.27	80
4,5	1.6[b]	5	1.0	82
6	1.6[c]	5.3	1.0	83

a = Maximum possible yield of dry solids for producing a 3/16 inch thick filter cake, at 33% submergence and a 0.8 scale-up factor.
b = 24% $Ca(OH)_2$ by weight added for conditioning.
c = 47% $Ca(OH)_2$ by weight added for conditioning.

TABLE 5 S

Condensation of Tables 5 & 7, Alum Treatment

Run No.		A-1	A-2
Duration (da.)		13	12
Al^{+++} (mg/l)		13	13
Polymer Type		none	Atlasep 3A3
Polymer Dose		0	0.25
Reaction Zone Solids (g/l)		0.8	0.6
Blowdown Volume, % of flow		6.2	3.5
Blowdown Concn. (g/l)		1.8	4.4
Suspended Solids,	In (mg/l)	82	110
	Out (mg/l)	24	30
Total P,	In (mg/l)	4.4	5.8
	Out (mg/l)	1.0	1.2
Soluble TOC,	In (mg/l)	24	26
	Out (mg/l)	19	15
Total Sludge, lb/MG Influent		930	1280
Total Sludge, mg/l Influent		112	154
Chemical Sludge, mg/l Influent		54	74
lb. chemical solids/lb Al fed		4.2	5.7

TABLE 8: ALUM TREATMENT: VACUUM FILTRATION LEAF TEST DATA

Test #	1	2
Feed Solids, % by wgt	0.70	0.36
Cycle Time, Minutes	8	23
Yield[a], lbs/hr-ft^2	0.38	0.14
Cake Moisture, % by wgt	85	77
Polymer Type	anionic	cationic
Polymer Dosage, lbs/ton of Dry Solids	8.6	14

---

[a] - Maximum possible rate for producing a dischargeable 3/16 inch thick cake, @33% submergence and 0.8 scale - up factor

TABLE 9 S

Condensation of Table 9, Lime Treatment

Run No.		3	4	5	6	7	8	9	10	11
Duration (da.)		16	20	16	16	23	24	8	20	25
$Ca(OH)_2$ dose (mg/l)		425	365	420	390	526	490	586	950 av.	1530
Reaction Zone pH		10.8	10.8	10.8	10.9	10.9	11.0	11.0	11.45av.	11.6
Reaction Zone Solids (g/l)		8.6	-	2.1	1.9	3.8	12	2.2	5.8	4.4
Blowdown volume, % of flow		0.49	0.88	0.75	0.45	1.4	0.40	1.5	1.4	2.8
Blowdown concn. (g/l)		190	100	64	113	81	185	54	54	42
Suspended Solids, in (mg/l)		100	170	92	56	120	58	92	72	170
, out (mg/l)		16	8.0	13	12	7.0	17	1.7	6.0	6.5
Total P	, in (mg/l)	7.2	6.7	3.8	-	8.0	5.3	4.9	3.8	7.8
	, out (mg/l)	1.1	1.3	0.3	-	1.6	1.0	1.0	0.5	1.0
Soluble TOC	, in (mg/l)	22	-	23	22	24	-	19	-	-
	, out (mg/l)	18	-	25	26	24	-	20	-	-
pH, in		7.5	7.6	7.6	7.5	7.5	7.8	7.5	7.6	7.5
, out		8.0	7.6	7.9	7.8	7.7	7.3	7.6	6.8	7.6
Alkalinity	in	275	306	336	312	341	313	364	316	330
as $CaCO_3$ (mg/l)	out	110	62	123	89	63	54	62	67	80
Total hardness	in	383	404	465	433	444	383	503	392	464
as $CaCO_3$ (mg/l)	out	335	327	410	406	367	320	469	543	1550
Ca^{++}hardness	in	230	251	280	270	255	229	283	216	280
as $CaCO_3$ (mg/l)	out	265	265	263	309	297	265	409	512	1500

TABLE 10 S

Comparison of Measured Sludge Quantities with Calculated Quantities

Run No.	3	4	5	6	7	8	9	10	11
Measured Sludge Quantity									
Total Sludge, lb/MG Influent	9170	7010	5250	5840	8340	7340	7260	6300	12,100
Total Sludge, mg/l Influent	1100	842	630	700	1000	880	872	756	1450
Chemical Sludge, mg/l Influent	1016	680	551	656	887	839	782	690	1287
lb Chem. Sludge/lb $Ca(OH)_2$	2.39	1.86	1.31	1.68	1.68	1.70	1.33	0.73	0.84
Calculated Sludge Quantity									
Δ HCO_3, as $CaCO_3$ (mg/l)	165	244	213	223	278	259	302	249	250
Δ CO_2, as $CaCO_3$ (mg/l)	15	12	12	14	19	5	20	-3	15
Δ Mg, as $CaCO_3$ (mg/l)	47	91	38	66	119	99	160	145	134
Δ P (mg/l)	est. 4.8	5.4	3.5	5.0	6.4	4.3	3.9	3.3	6.8
HAP produced (mg/l)	25.9	29.1	18.9	27.0	34.6	23.2	21.1	17.8	36.7
$CaCO_3$ formed (mg/l)	330	500	438	460	575	523	624	495	515
Mg $(OH)_2$ formed (mg/l)	47.3	51.9	21.7	37.6	68	56.4	91.3	82.8	76.5
Ca^{++}not accounted for (mg/l)	68	-37.5	51.2	-2.9	23.4	33	7.0	190	121
Calc. Sludge Quantity (mg/l) (HAP+$CaCO_3$+$Mg(OH)_2$	418	581	479	525	678	602	736	596	628
Measured vs. Calculated									
Ratio: Measured/Calc.	2.43	1.17	1.15	1.25	1.31	1.39	1.06	1.16	2.05
Calc. sludge incl. Ca^{++} not accounted for(as $Ca(OH)_2$)(mg/l)	544	-	574	525	721	663	749	948	852
Meas./(Calc. + Ca^{++})	1.86		0.96	1.25	1.23	1.26	1.04	0.73	1.51

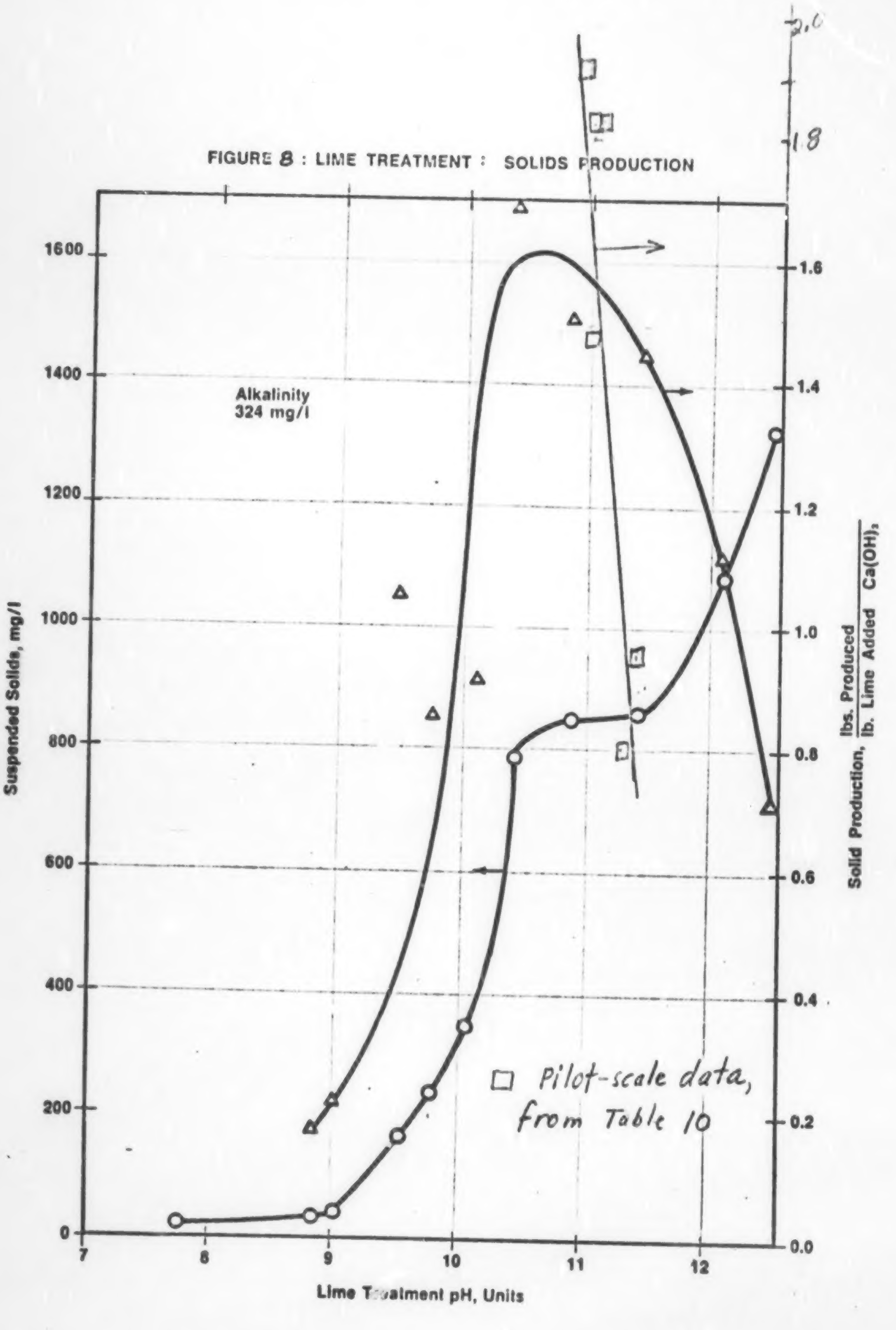
TABLE 11: SUGGESTED DESIGN PARAMETERS FOR SLUDGE THICKENING AND DEWATERING

Item	Treatment pH Moderate <11.0	 High >11.5
Chemical Clarifier underflow concentration (weighted avg., of all data), % by weight	11.5	4.8
Predicted thickener underflow solids - % by weight[a]	17.9	9.4
Predicted thickener solids loading - lbs/day-ft^{2}[a]	51	18
Predicted vacuum filter yield - lbs/hr-ft^{2}[b]	12.8	4.3
Filter cake form time - min (from leaf test results)	0.6	1.0
Modified correlating factor-min-ft^{2}/lb (includes 0.8 scale-up factor)	1.9	5.4
Filter Cake moisture - % by weight[c]	67	72

a = from Figure 35
b = from Figure 37
c = from Figure 38

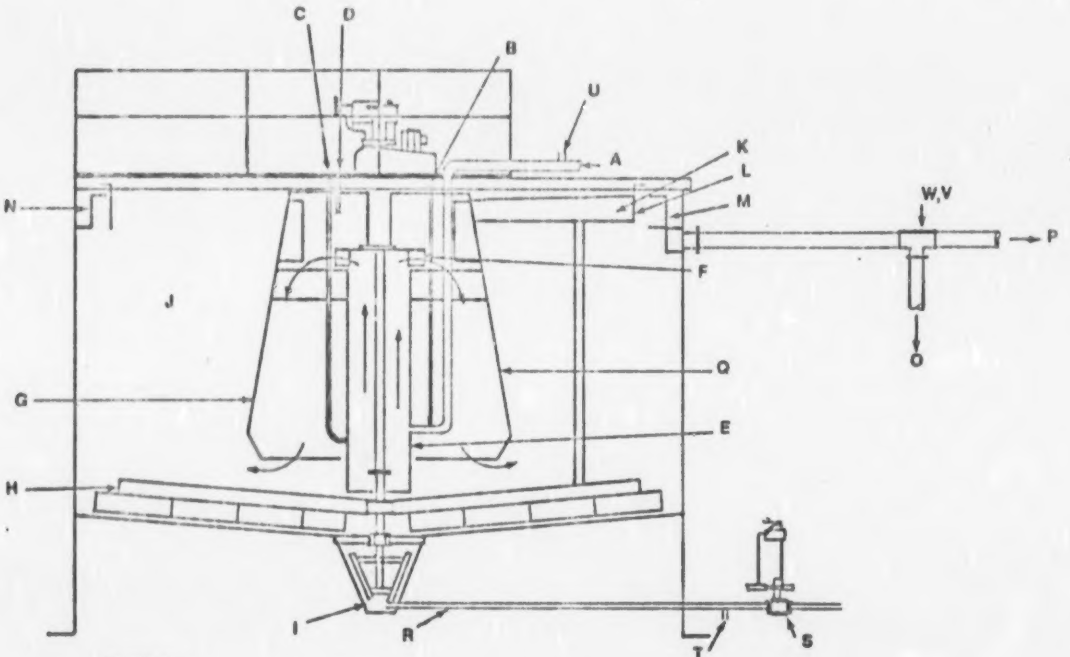
Note: All thickening data (including sludge density after 24 hr) were determined using Eimco's standard thickening test: 2000 ml of sludge settled in a 2-liter graduate, stirred at 6 rev./hr., using a "picket" stirrer comprised of 4 vertical wires.

FIGURE 8 : LIME TREATMENT : SOLIDS PRODUCTION



□ Pilot-scale data, from Table 10

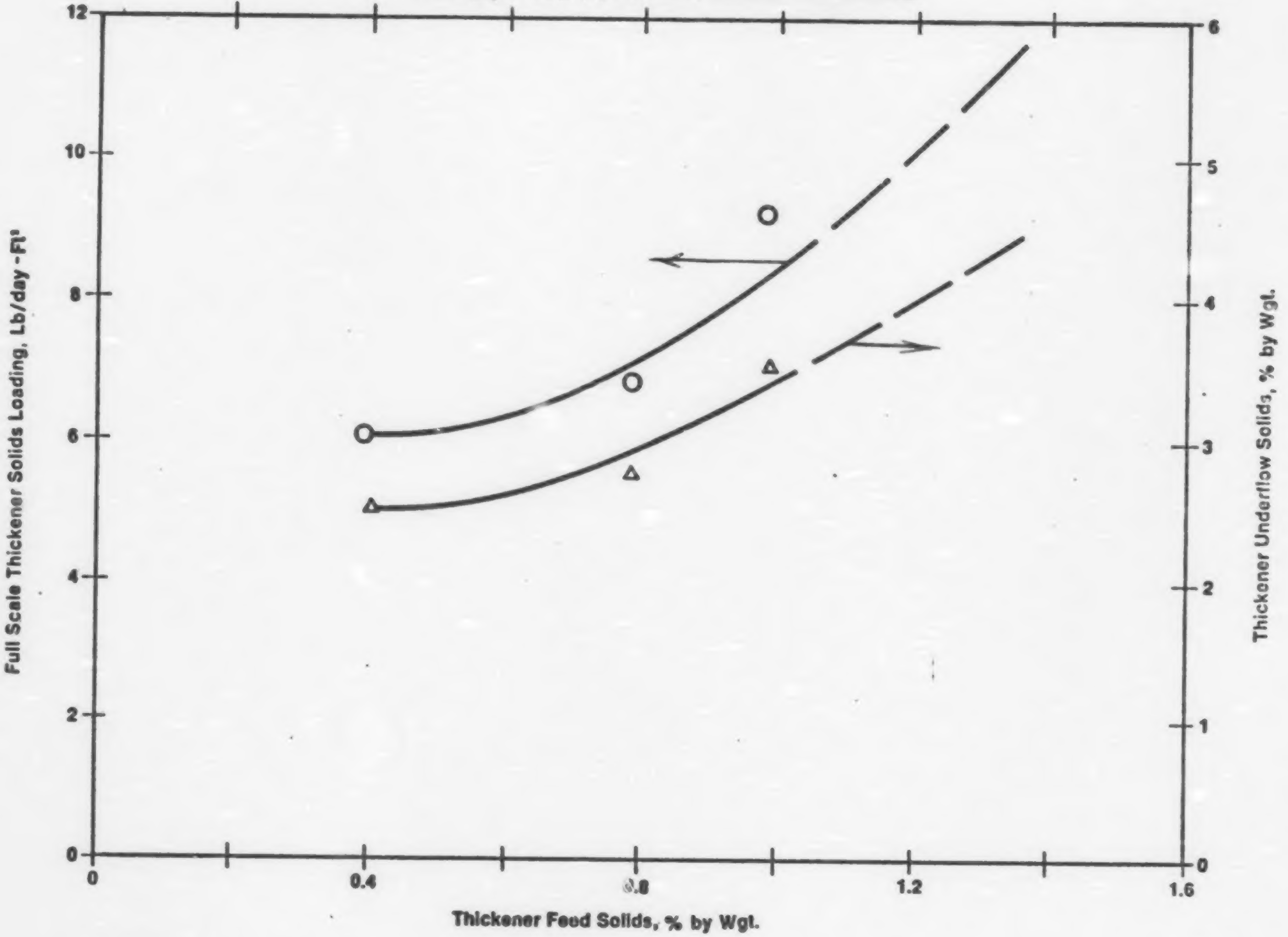
FIGURE 15: EIMCO REACTOR-CLARIFIER, SOLIDS-CONTACT CHEMICAL TREATMENT UNIT (RC-1)



Symbols:

A. Influent Pipe
B. Inorganic Coagulant Feed
C. Lime Feed
D. Polymer Feed
E. Draft Tube
F. Pumping Turbine
G. Sample Point, Reaction Zone
H. Sludge Rake
I. Sludge Thickening Cone
J. Expanding Area Clarification Zone
K. Liquid Surface Skimmer
L. Float Baffle
M. Peripherial V-Notched Launder
N. Acid Feed Point
O. Effluent to First Carbon Contactor
P. Effluent to Second Carbon Contactor or Drain
Q. Reaction Zone Cone
R. Sludge Blowdown Line
S. Timer Controlled Sludge Valve
T. Process Water Blowback Valve
U. Vacuum Breaker
V. Effluent Sample Point
W. Flow Splitter Box

FIGURE 24: $FeCl_3$ TREATMENT: SLUDGE THICKENING



*See footnote to Table 11.

FIGURE 32: LIME TREATMENT: SLUDGE PRODUCTION

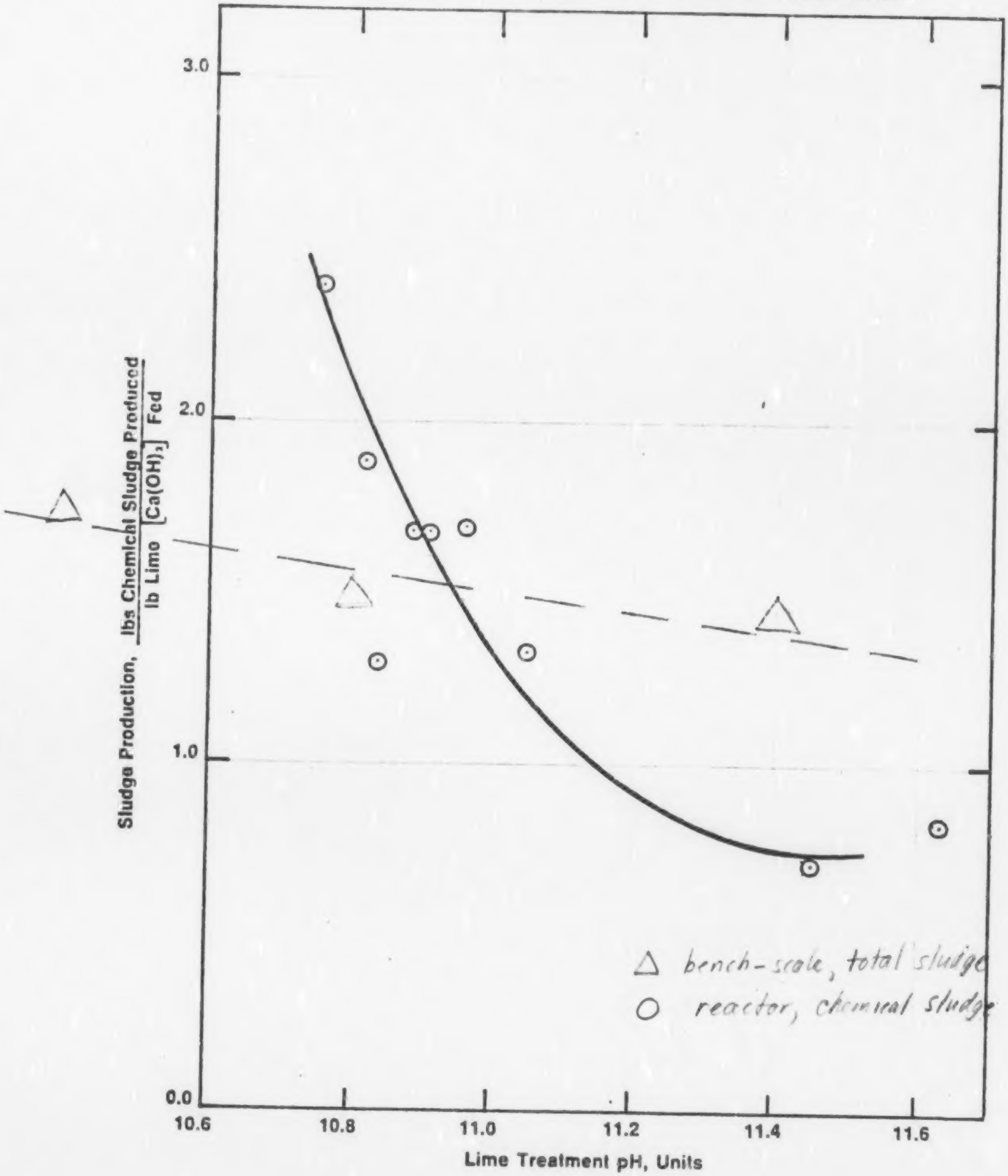


FIGURE 32 S

CHEMICAL SLUDGE PRODUCED BY LIME ADDITION

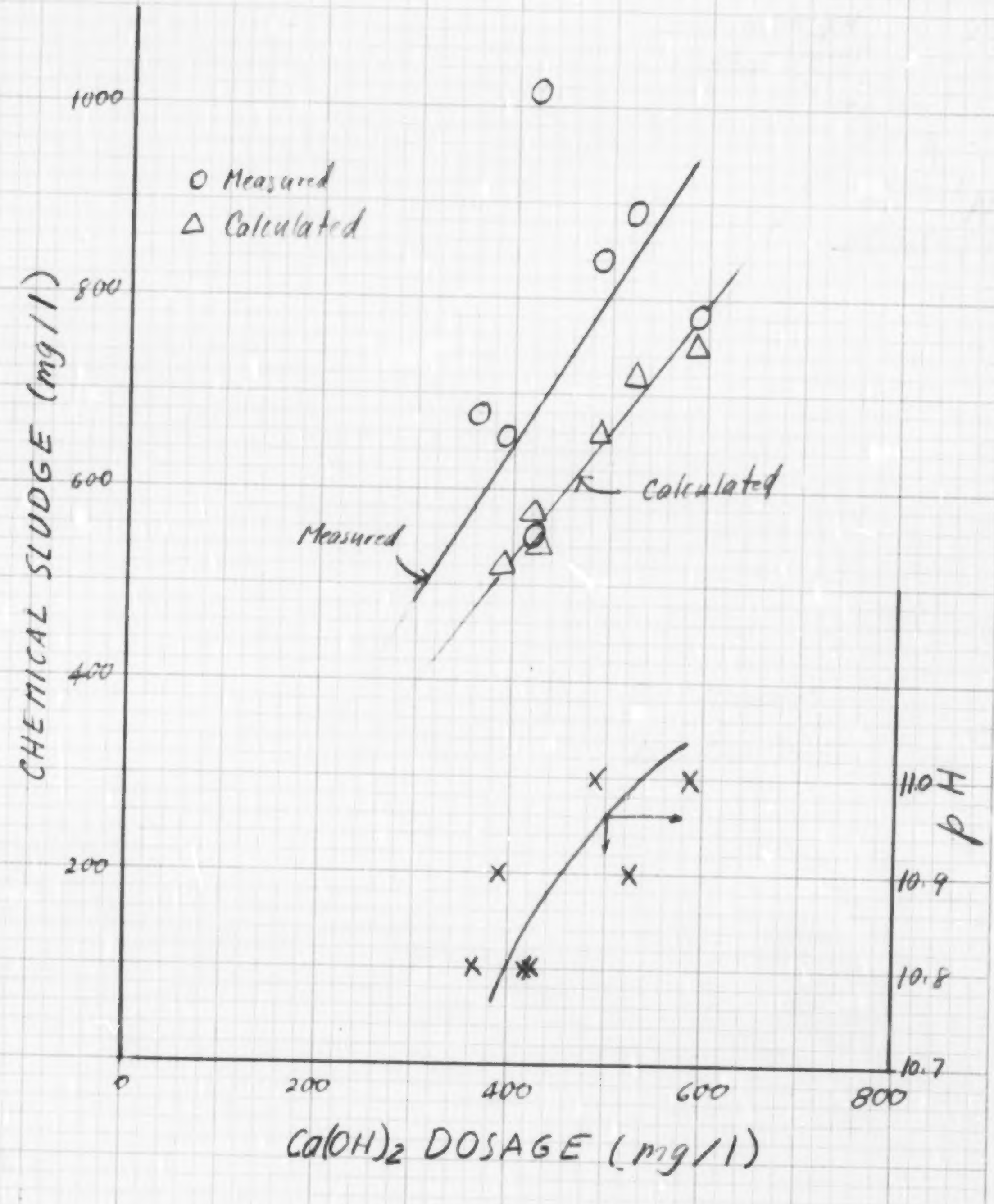


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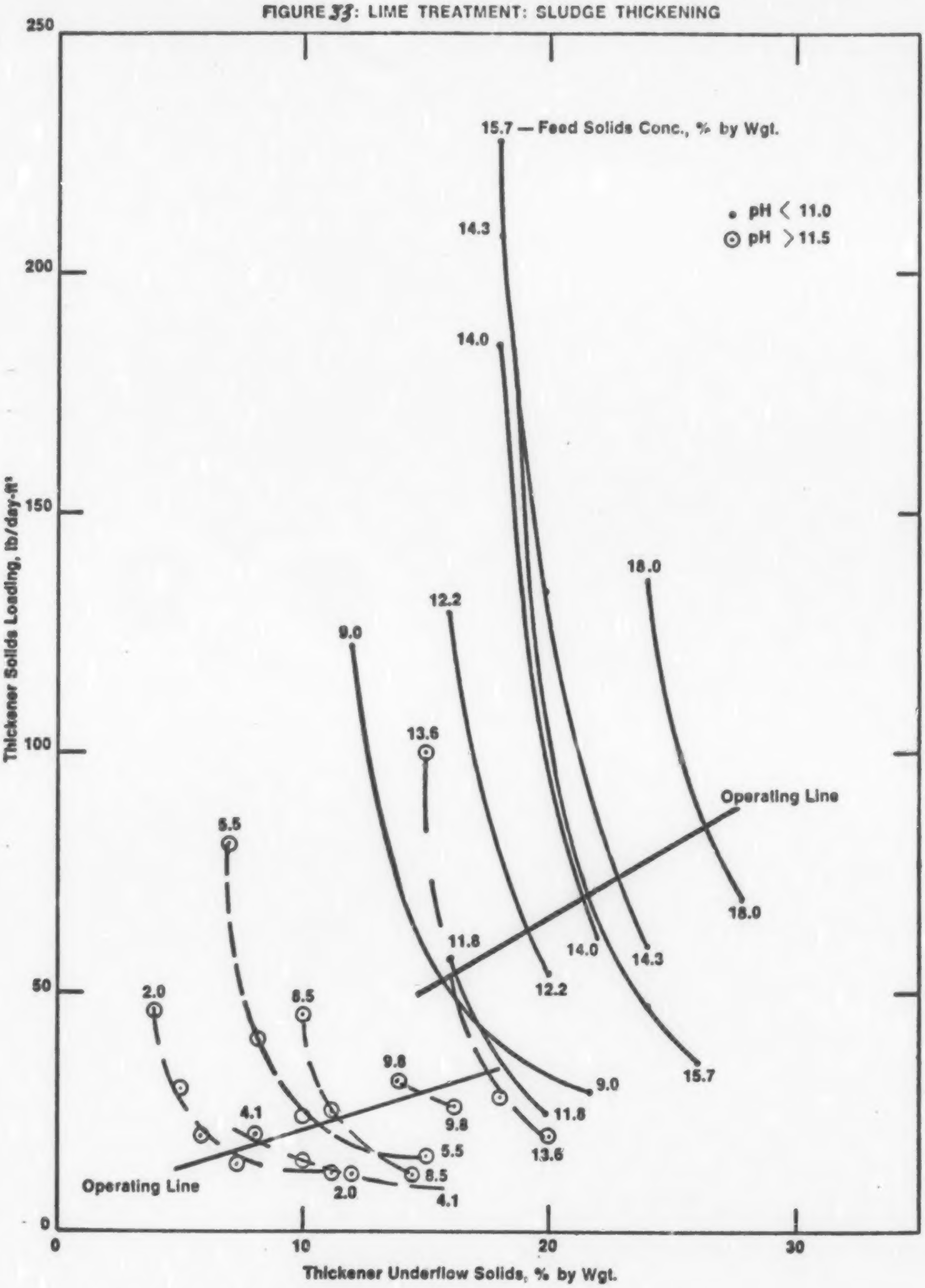
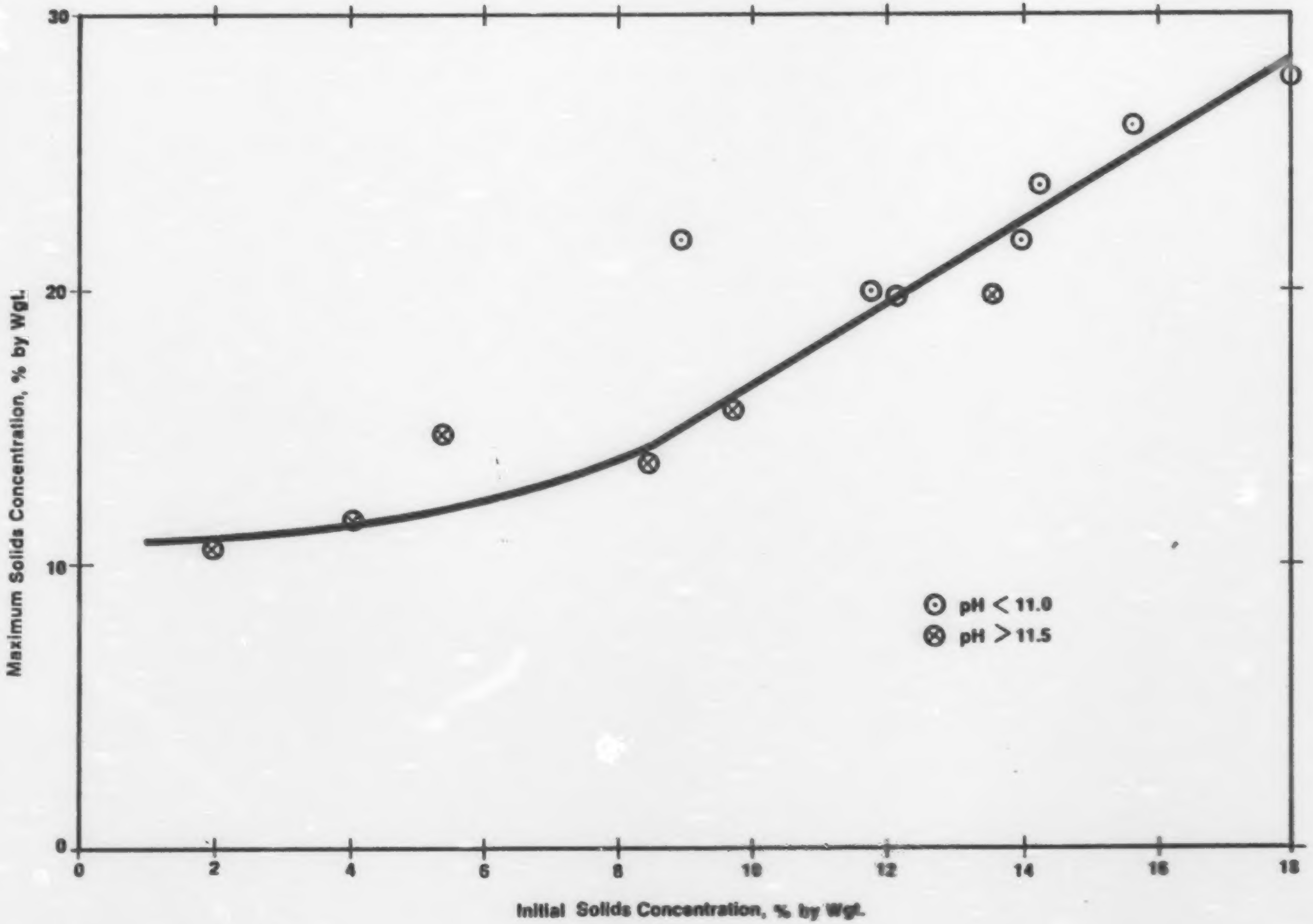
FIGURE 33: LIME TREATMENT: SLUDGE THICKENING



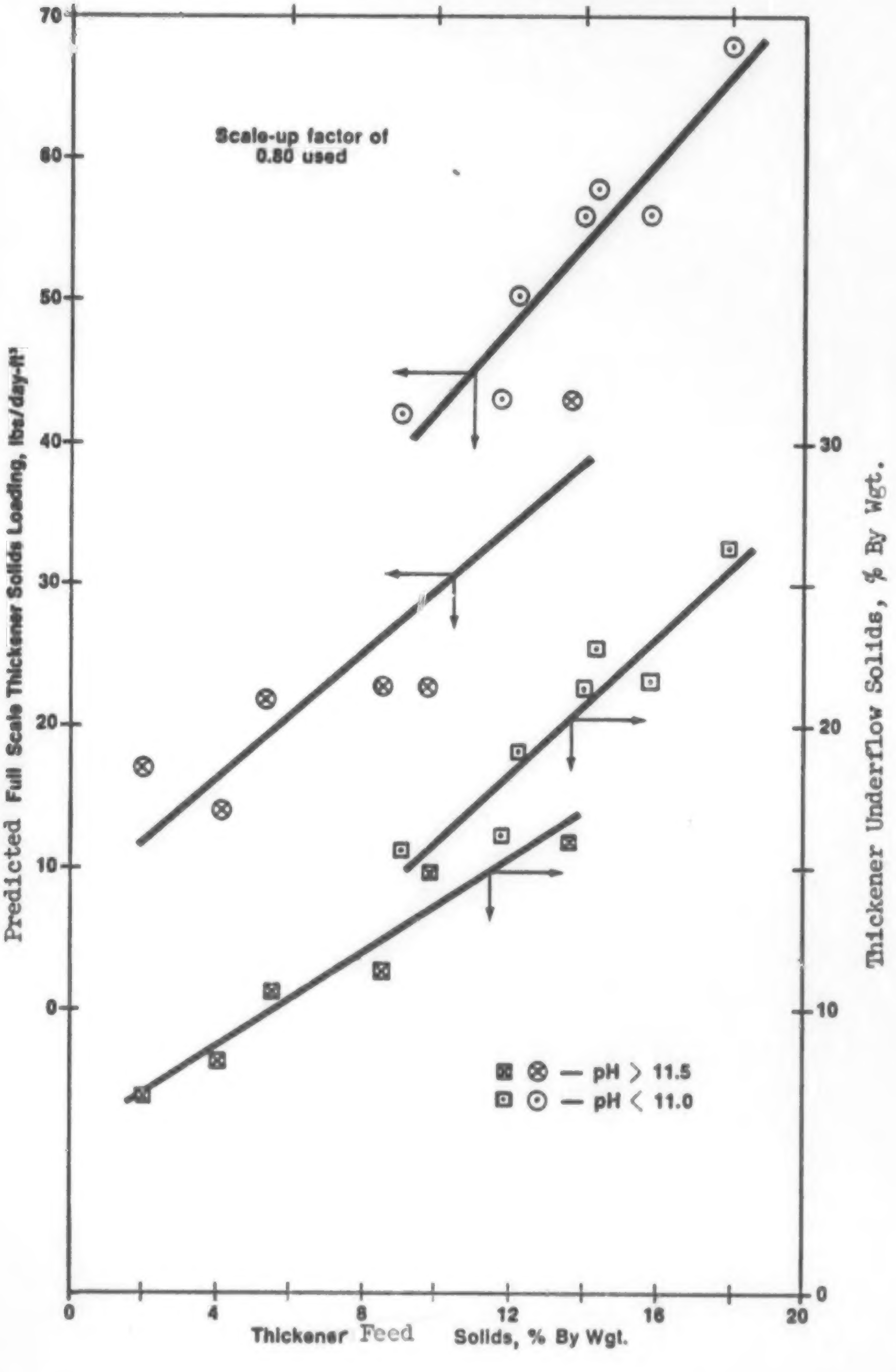
*See footnote to Table 11.

FIGURE 34: LIME TREATMENT: SLUDGE THICKENING



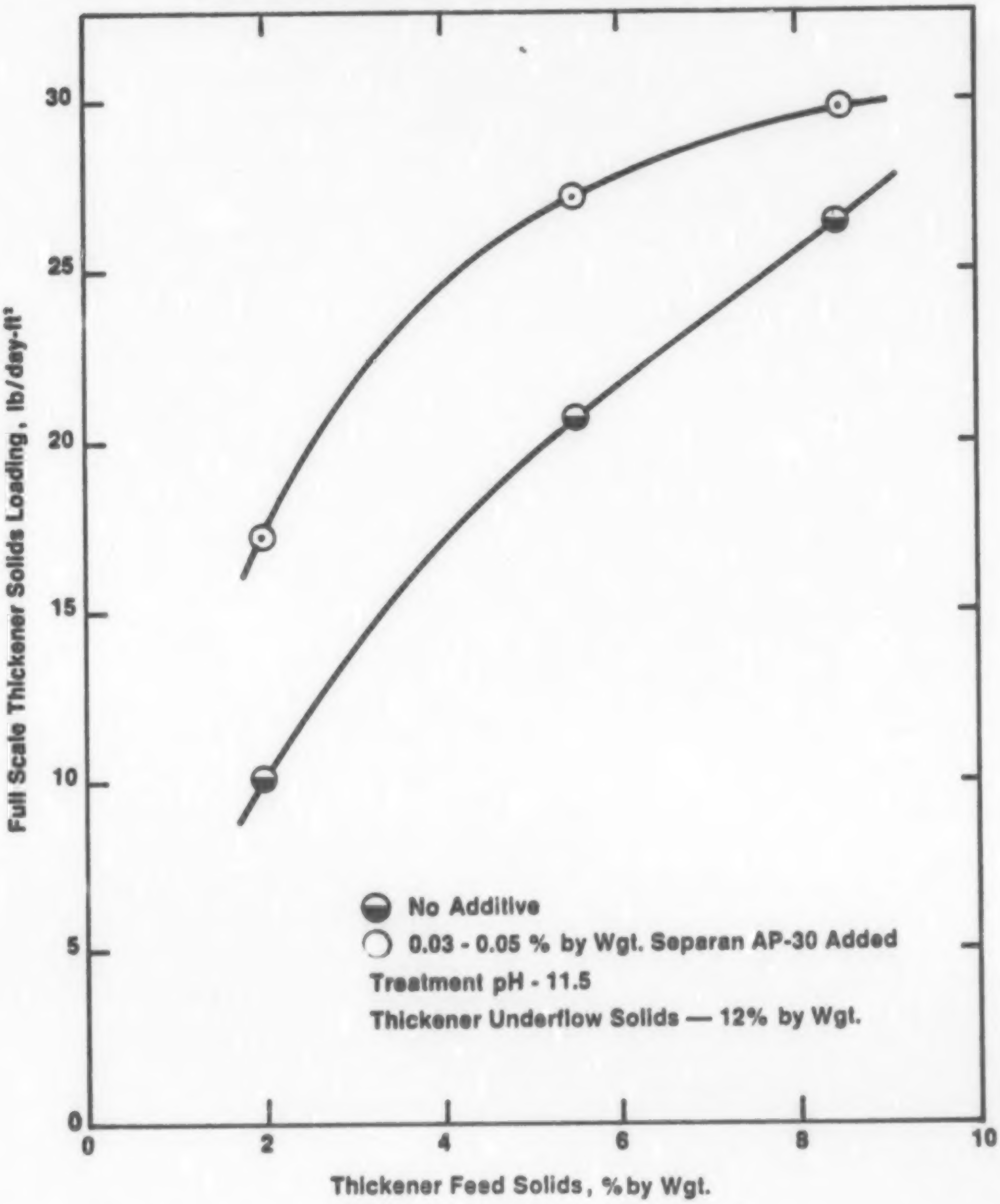
*See footnote to Table 11.

FIGURE 35 : LIME TREATMENT: SLUDGE THICKENING



*See footnote to Table 11.

FIGURE 36: LIME TREATMENT: SLUDGE THICKENING



*See footnote to Table 11.

FIGURE 37: LIME TREATMENT: SLUDGE DEWATERING

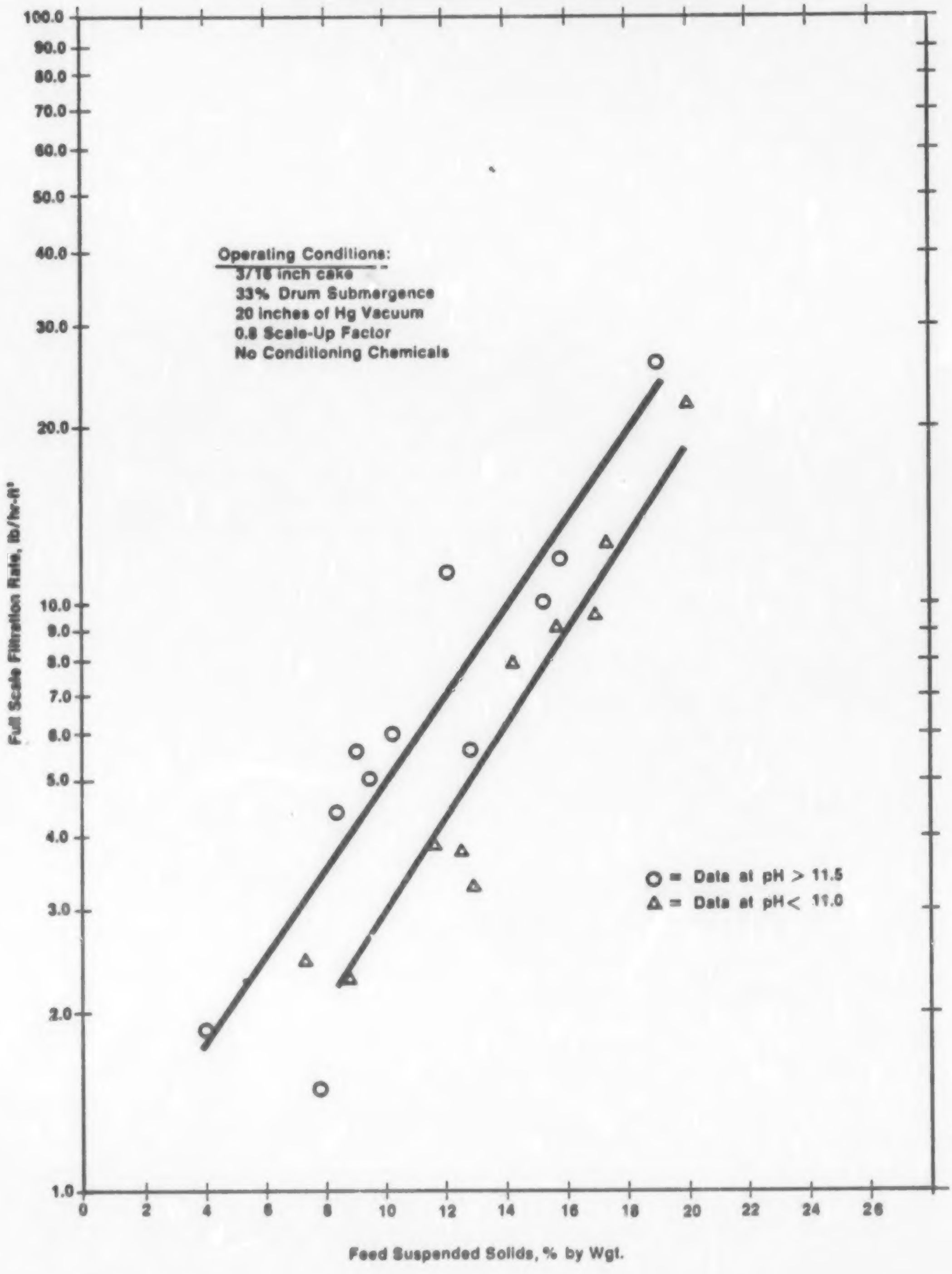
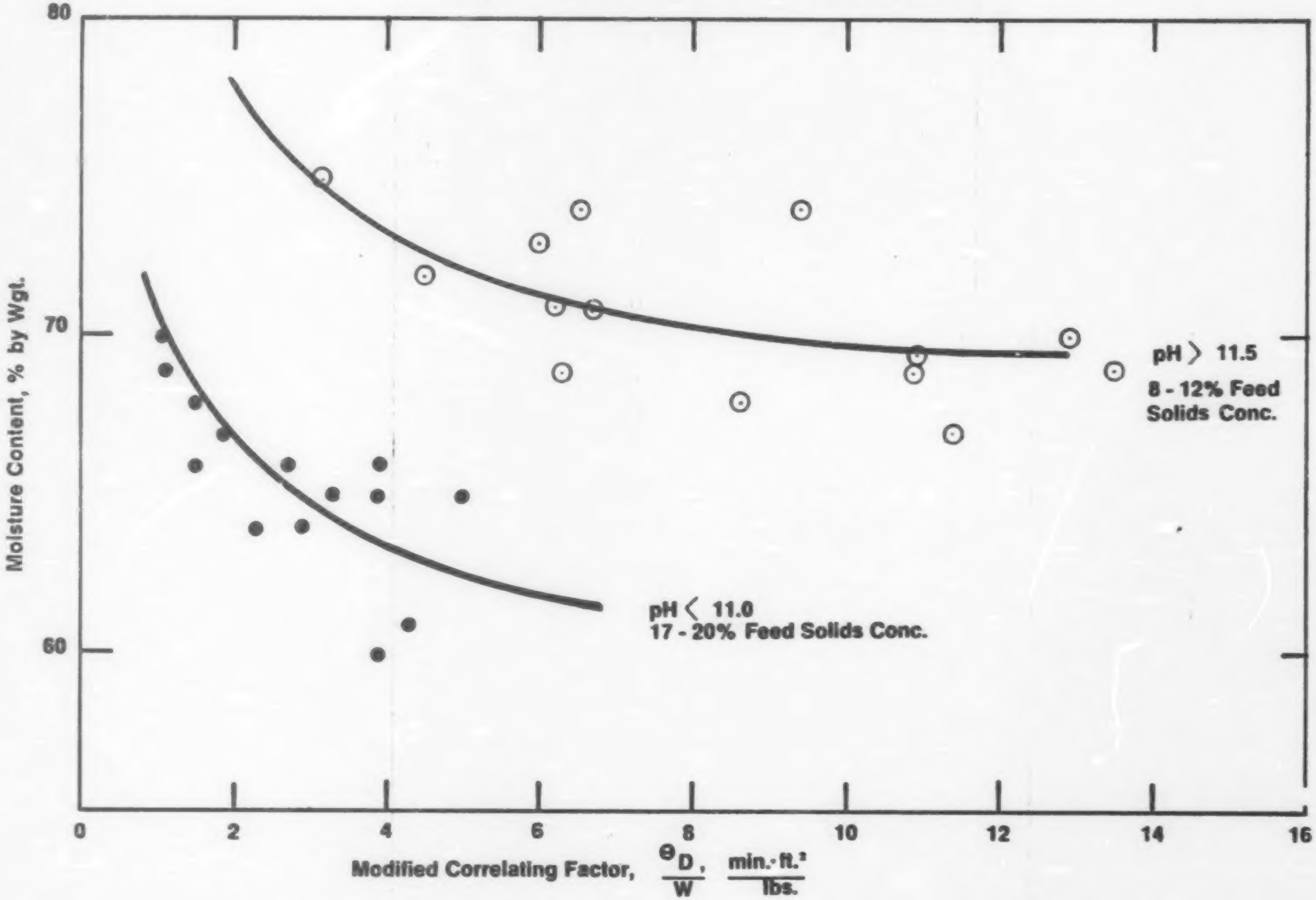


FIGURE 38: LIME TREATMENT: SLUDGE DEWATERING



APPENDIX F

SLUDGE INFORMATION SUMMARY NO. 2 - SOUTH TAHOE

Type of Sludge

Raw mixed primary and waste activated (centrifuged); sludge from treatment of secondary effluent with recalcined lime (centrifuged).

Source of Information

Final report: "Advanced Waste Treatment as Practiced at South Tahoe," EPA No. 17010 ELQ 08/71, pub. Aug. 1971, available from Supt. of Documents.

Author: South Tahoe Public Utility District
(D. R. Evans, J. C. Wilson, R. L. Culp)
South Lake Tahoe, California

EPA Project Officers and Technical Backup:
J. C. Merrell, J. Troyan, R. Wills, R. B. Dean

Author of Summary

J. B. Farrell
Ultimate Disposal Research Program
EPA, NERC
Cincinnati, Ohio 45268

Date Prepared June 6, 1972 8 pp.

Objective of Summary

This and similar summaries attempt to extract information on sludges from reports of investigations on wastewater treatment. Such reports are often lengthy, and their primary objectives are unrelated to sludge disposal. The "Sludge Information Summary" condenses the information on sludges into a few pages. Where possible, results are related to other studies, and judgements are made by the summary author regarding the value of the results. For the most part, however, the data and observations of the report author are accepted at face value and merely recorded in the summary.

Introduction

At South Lake Tahoe, wastewater receives primary treatment, followed by activated sludge treatment. Waste activated sludge is returned to the primary clarifier and is removed with the primary sludge. The mixed sludge from the primary clarifier is pumped to a solid bowl centrifuge for dewatering and is then incinerated. The secondary effluent is further treated with lime, clarified, passed through an air scrubber to remove ammonia, and is then recarbonated. The effluent is further treated by filtration and carbon adsorption. Sludges from the lime clarifier and recarbonation basin are combined and thickened, and finally dewatered in a solid bowl centrifuge. The sludge cake is calcined and recycled for reuse along with makeup lime in the lime clarifier. Since lime and phosphate react to form insoluble hydroxyapatite, some of the sludge from lime clarification must be discarded to prevent a buildup of inerts in the recycled lime stream.

This summary is restricted to a description of the thickening and dewatering of the sludge from the primary clarifier and the sludge from the lime treatment. The report gives details of the incineration and calcination of these sludges; however, this summary does not include this information.

A. Dewatering of Waste Organic Solids

A flow sheet of the waste organic solid dewatering system is attached. Excess activated sludge is wasted to the primary clarifier where it settles with the primary sludge. The combined sludge is pumped from the primary clarifier at 1-2% solids through a cyclone degritter to a small holding tank. No thickening occurs in the holding tank. The sludge is pumped to a centrifuge and dewatered with over 90% capture, producing a cake with about 18% solids. Centrate returns to the primary. About 2 to 5 lbs. of a polyelectrolyte per ton of dry solids is needed to increase the recovery in the centrifuge.

Data for December 1969 - December 1970 are given below:

Plant Influent	2.45 MGD
Centrifugal (Bird Solid Bowl Concurrent Flow, 24"x60", 75 HP)	
Feed solids	2.0%
Cake solids	17.0%
Polyelectrolyte	5.1 lb/ton*
Sludge to Incinerator	
Feed, dry solids	921 tons*

Sludge is incinerated along with waste lime sludge solids. Tons are measured only at the incinerator and include the lime waste solids. Tonnage figures in the table above (see asterisks) include the lime waste. Thus, polyelectrolyte dose based on the amount of primary and activated sludge is actually higher than noted above and production of primary and activated sludge is lower than noted. Sludge production calculated from the table above amounts to 1.06 tons/million gallons of influent. From the foregoing, it is evident that this is a maximum figure.

B. Lime Treatment and Sludge Dewatering

1. Lime Treatment - Secondary effluent is treated with a mixture of makeup and recalcined lime fed as a $Ca(OH)_2$ slurry. The proportion of makeup to recalcined lime is approximately 1 to 3. The pH is raised to 11, and requires approximately 300 mg/l of active CaO. Phosphorus-rich lime mud settles out in a clarifier. Approximately 0.1 to 0.3 mg/l of a

polymer is added to improve clarification. Effluent is recarbonated in a two-stage recarbonation basin. The pH is reduced to about 9.6 in the first stage. At this pH, solubility of Ca^{++} is a minimum and recovery of $CaCO_3$ is maximized. The pH is reduced in the second stage to about 7.2 by further recarbonation. Clarifier and carbonation sludge are pumped to a thickener.

2. Sludge Thickening - The sludge thickener is a cylindrical vessel, 30 feet in diameter. Design criteria were as follows:

Flow	450 gpm (0.65 MGD)
Surface overflow rate	1,000 gal/da.ft^2
Surface dry solids loading	200 lb/da.ft^2
Thickened sludge solids	8 - 20%

The thickener can consistently produce 8% solids sludge. Some data are presented below:

	Test 1	Test 2
Input to clarifier	2.8 MGD	3.7 MGD
Input to thickener (est.)	0.25 MGD	0.18 MGD
Influent solids	ca. 1%	ca. 1%
Underflow rate	0.052 MGD	0.022 MGD
Lime mud solids	4.9%	8.3%

The input to the thickener was estimated by the writer from the underflow rate and the influent and lime mud solids concentration given in this table.

The thickener was hardly tested since it was operated at less than half of capacity. Losses of usable calcium over the weirs was 0.04% in one test. Sludge is readily thickened to 8% solids.

3. Dewatering - A flow sheet of the lime sludge dewatering system is attached. Thickened lime mud is pumped for dewatering to a Bird 24"x 60" solid bowl concurrent flow centrifuge (75 HP). The centrifuge is deliberately operated with high losses to the centrate in order to classify out organics,

magnesium oxide, and hydroxyapatite, leaving behind a high concentration of calcium carbonate in the cake. The cake is calcined and its lime value recovered. The centrate is sent to a second centrifuge of the same type where the remaining solids are brought down and removed as a 30% solids cake.

The centrifuges can be operated at 2200, 1800, or 1600 rpm. Initial tests were carried out on the lime mud feed stream to determine optimum operating speed. Data showed approximately the same percent solids in the cake and the same recovery of solids at all three speeds. The lowest speed was selected to reduce wear and maintenance.

The percent capture or recovery of lime mud feed solids into the cake decreased linearly with increasing feed rate of lime mud. At approximately 8 percent solids in the feed, the following results were obtained:

feed rate (gpm)	% Capture
10	93
20	79

The fractional losses to the centrate of phosphate, lime, and magnesium oxide were nearly directly proportional to the total loss of mass to the centrate. The following tabulation from unpublished data (Farrell, Evans, and Wilson, July 1970 at Lake Tahoe) indicates the relationship:

	Fraction lost to the Centrate		
Total Solids	Active lime	Phosphate	MgO
0.05	0.02	0.1	0.09
0.10	0.04	0.19	0.17
0.15	0.06	0.29	0.26
0.20	0.08	0.39	0.35

Approximate composition of the solids in the feed during these tests (after calcining) was 29% hydroxyapatite, 56% active lime and 3% MgO. Results were independent of feed rate in the range examined (ca. 14-20 gpm).

Data should not be extrapolated much above 20% loss of solids to the centrate.

In the authors' Figure 46, the data are about the same as in the above table except for one data point. This point indicates a much higher phosphate removal: 96% of the phosphate is lost to the centrate at 24% total solids lost to the centrate. In this writer's opinion, this is an unusual result and depends on a single data point. The recoveries suggested in the above table are more conservative than the authors' Figure 46 and, with the limitations noted, are recommended by this writer. Under normal operating conditions, the cake leaving the lime mud centrifuge ranges from 36-38% solids. The cake leaving the centrifuge fed with centrate from the first centrifuge averages about 30% solids.

4. Quantities of Lime Sludge - Measurement of the quantity of lime sludge produced related to the plant influent could not be carried out. The authors state (p 139) that at a flow of 7.5 MGD through the water reclamation plant the total blowdown of waste solids from the lime clarification operation would be about 17 tons per day of lime mud (dry CaO basis) if there were no lime recovery. With lime recovery, this quantity is reduced to about 1.5 tons per day. It is not completely clear what is meant by "dry CaO basis." The 17 tons/day amounts to 543 mg per liter. This writer interprets this to mean 543 mg of dry lime sludge per liter of influent.

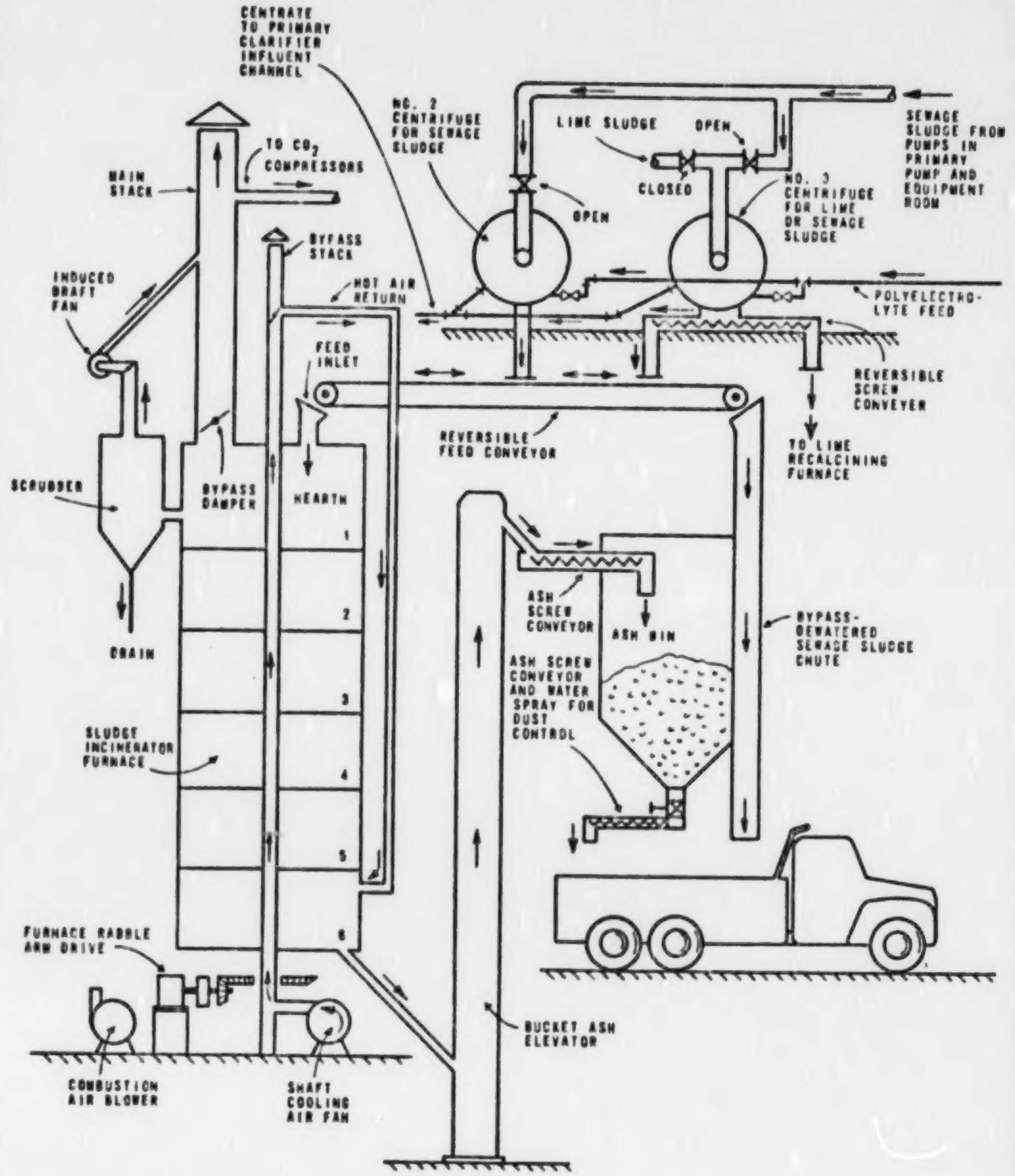

CENTRATE TO PRIMARY CLARIFIER INFLUENT CHANNEL
NO. 2 CENTRIFUGE FOR SEWAGE SLUDGE
LIME SLUDGE
OPEN
SEWAGE SLUDGE FROM PUMPS IN PRIMARY PUMP AND EQUIPMENT ROOM
TO CO_2 COMPRESSORS
MAIN STACK
CLOSED
NO. 3 CENTRIFUGE FOR LIME OR SEWAGE SLUDGE
OPEN
BYPASS STACK
INDUCED DRAFT FAN
HOT AIR RETURN
POLYELECTROLYTE FEED
FEED INLET
REVERSIBLE SCREW CONVEYER
REVERSIBLE FEED CONVEYOR
TO LIME RECALCINING FURNACE
SCRUBBER
BYPASS DAMPER
HEARTH
1
2
3
4
5
6
ASH SCREW CONVEYOR
ASH BIN
BYPASS-DEWATERED SEWAGE SLUDGE CHUTE
DRAIN
ASH SCREW CONVEYOR AND WATER SPRAY FOR DUST CONTROL
SLUDGE INCINERATOR FURNACE
FURNACE RABBLE ARM DRIVE
BUCKET ASH ELEVATOR
COMBUSTION AIR BLOWER
SHAFT COOLING AIR FAN

FIGURE 9
SOLIDS HANDLING
PRIMARY AND SECONDARY SLUDGE

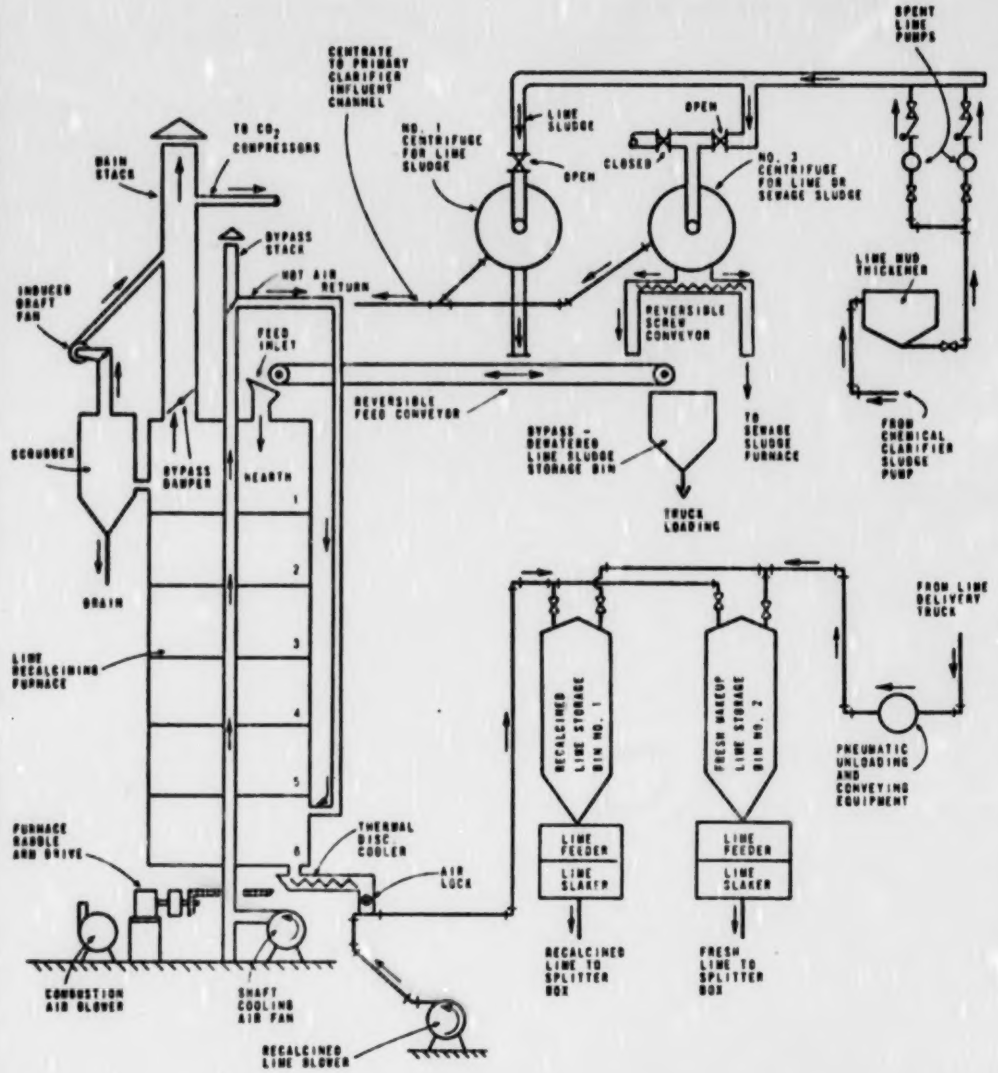

SPENT LIME PUMPS
CENTRATE TO PRIMARY CLARIFIER INFLUENT CHANNEL
TO CO$_2$ COMPRESSORS
MAIN STACK
LIME SLUDGE
OPEN
NO. 1 CENTRIFUGE FOR LIME SLUDGE
OPEN
CLOSED
NO. 3 CENTRIFUGE FOR LIME OR SEWAGE SLUDGE
BYPASS STACK
HOT AIR RETURN
INDUCED DRAFT FAN
LIME MUD THICKENER
REVERSIBLE SCREW CONVEYOR
FEED INLET
REVERSIBLE FEED CONVEYOR
SCRUBBER
BYPASS DAMPER
HEARTH
1
2
3
4
5
6
BYPASS - DEWATERED LIME SLUDGE STORAGE BIN
TO SEWAGE SLUDGE FURNACE
FROM CHEMICAL CLARIFIER SLUDGE PUMP
TRUCK LOADING
DRAIN
FROM LIME DELIVERY TRUCK
LIME RECALCINING FURNACE
RECALCINED LIME STORAGE BIN NO. 1
FRESH MAKEUP LIME STORAGE BIN NO. 2
PNEUMATIC UNLOADING AND CONVEYING EQUIPMENT
FURNACE RABBLE AND DRIVE
THERMAL DISC. COOLER
AIR LOCK
LIME FEEDER
LIME SLAKER
LIME FEEDER
LIME SLAKER
COMBUSTION AIR BLOWER
SHAFT COOLING AIR FAN
RECALCINED LIME TO SPLITTER BOX
FRESH LIME TO SPLITTER BOX
RECALCINED LIME BLOWER

FIGURE 41
SOLIDS HANDLING
LIME SLUDGE

September 6, 1973

APPENDIX G

FIELD TRIP REPORT NO. 3

Title:	"Characteristics of Lime Sludge from a Tertiary Treatment Plant
Objective:	Determine the characteristics of the sludge produced when the secondary effluent from a trickling filter plant is treated with lime to remove phosphate.
Site Visited:	0.40 MGD Wastewater Treatment Plant, Butler, Indiana
Persons Contacted:	Mr. Richard Miller, Plant Superintendent Mr. Anthony (Tony) Yaar, Consultant from Clyde E. Williams and Associates, South Bend, Indiana
Field Trip Personnel	Mr. Gerald Stern, Supervisor Mr. Oscar L. Grant
Period of Visit:	January 23-25, 1973
Author of Report:	Gerald Stern

Gerald Stern

APPROVED: Joseph B. Farrell

DATE: Oct 18, 1973

FIELD TRIP REPORT NO. 3

BACKGROUND:

Butler, Indiana, is a rural community of 2400 population with virtually no industrial contribution to the wastewater. The raw water supply comes from two wells (160 feet apart) and is used unchlorinated. The water is hard. Table 1 lists the well water chemical analysis as furnished by Wastewater Treatment Plant Superintendent. Because of its chemical properties, this wastewater is suited for single stage tertiary lime treatment for the 80 percent phosphate reduction required.

Data on tertiary treatment by lime are available at this date from three sources: Lake Tahoe (1), Blue Plains Pilot Plant (2), and Mulbarger's bench-scale work (3). Lake Tahoe and Blue Plains have low hardness water. Although Mulbarger's work is on moderately hard waters (Lebanon and Batavia, Ohio), it was felt that additional data on hard water using lime treatment on a plant scale would be desirable. For this reason, a limited field test was planned at the wastewater plant in Butler, Indiana, where a secondary effluent is being treated with lime, primarily for phosphate removal.

The Butler plant does not dewater the tertiary lime sludge but merely **discharges** it to a lagoon. Nevertheless, the sludge is produced on a plant scale and should be more typical of plant operation then, for example, the sludge produced in Mulbarger's batchwise, bench-scale experiments.

This field trip objective was to collect and characterize tertiary lime sludge as discharged from the reactor-clarifier, at the end of an 8-inch diameter--3,000-foot line where the sludge enters the lagoon, and from the lagoon itself. Characteristics investigated were settled sludge density, sludge thickening rate, specific resistance and sludge filtrability as determined by filter leaf tests. Because tertiary lime sludges dewater readily, no chemicals were added to condition the lime sludges.

WASTEWATER TREATMENT PLANT

The wastewater at Butler is collected in a combined sewer. Daily flows vary from 0.2 to 1.0 MGD, depending on the precipitation. The nominal (average) flow is 0.4 MGD. The treatment facility is designed according to Ten States Standards which requires a plant capacity 2.5 times greater than the present average daily flows. Because of variables flows, a sluice gate has been installed in the sewer trunk line to approximately equalize the wastewater flow to the treatment facility. The trunk line acts as a flow equalizer, filling in high flow periods and draining when flow is low.

The biological treatment plant is comprised of a standard two-stage rock media trickling filter preceded by a primary clarifier. Using November and December 1972 as typical months, the average BOD removal plus other biological plant data are tabulated in Table 2. Trickling filter sludge, collected in the secondary clarifier, is recirculated to the primary clarifier. The mixed sludge is removed and stabilized by two 91°F heated anaerobic digesters. The digested sludge is dewatered on sand beds. The underdrain filtrate is recycled to the head end of the plant. Digested sludge is stored on the sand beds over the winter season. In the warmer months, this and new dewatered digested sludge is either trucked (about one hour round trip) to a spreading site or spread on grass in the treatment plant vicinity.

The tertiary treatment process comprises the following steps:

(a) 0.1 to 0.2 mg/l Calgon WT 2900 anionic polymer is added just after secondary clarification.

(b) 5 to 7 mg/l ferric chloride is added several seconds later.

(c) approximately 150 mg/l pebble lime (CaO) is added to the rapid mix section of the solids contact reactor-clarifier.

The solids contact reactor clarifier is a vertical cylindrical vessel containing an inner cone (base is downward). The rapid mix section is in the center of the cone. This section is used for rapid mixing of lime feed, wastewater and internally recirculating lime sludge. Overflow rate is 0.22 GPM/ft^2 (317 gal/ft^2 day) based on 0.4 MGD flow. This low overflow rate allows sufficient detention time for good liquid-solids separation.

The lime sludge is raked to a central exit at the bottom of the clarifier. A centrifugal pump discharges the sludge at approximately 150 GPM for one minute every two hours. The sludge is discharged through an 8-inch diameter pipe a distance of 3,000 feet to a lime sludge lagoon. Two lagoons are provided. When one fills up, flow will be switched to the other lagoon. The isolated lagoon will be allowed to dry out and sludge will be disposed of by landfill or land spreading on nearby land.

EXPERIMENTAL PROCEDURES

Sampling. Sludge could be sampled at two locations:

(a) Near the clarifier, in the control room, from a tap and valved 1/2 inch diameter hose located on the top of the 8-inch discharge line between two discharge pumps.

(b) At the end of the 3,000 foot pipe.

Both of these sample points had their disadvantages. The high pressure at the 1/2-inch tap caused a great deal of spraying. The discharge from the end of the 3,000-foot long, 8-inch diameter pipeline is very rapid at 150 GPM. In addition, the sludge discharging from the 3,000 foot pipeline could be as much as 5 days old since the internal volume of the pipeline is approximately 8,600 gallons and the average sludge discharge rate was about 1800 gallons per day. However, sludge samples were collected at both points, and also from the sludge lagoon near the pipeline discharge point about a foot under the sludge surface.

Grab samples of the municipal water and the wastewater as it progressed through the treatment sequences were collected for analyses. The municipal water sample was taken at the tap in the laboratory. The wastewater samples are: raw wastewater, secondary effluent, tertiary effluent before sulfuric acid pH adjustment and final effluent after pH adjustment. Table 3 shows the analyses summary. The constituent concentrations increase from the water to the raw wastewater as expected. Likewide, the changes in constituent concentrations from the raw wastewater to the final effluent is as expected for a single stage lime treatment at pH 10 on hard water. Total phosphorus removal is about 80 percent.

Daily Test Schedule. A limited amount of specialized testing equipment was brought to the site. In the two day visit, the following sludge tests were conducted:

Day 1 -- Arrived at wastewater plant 3:00 P.M. Set up test equipment. Collected sludge sample at the end of the 3,000 foot discharge pipe. Conducted 50 gallon gravity thickening test which continued overnight. Conducted stirred thickening test following the Eimco test procedure (see below). This test was also continued overnight. Conducted some Buchner funnel specific resistance tests, several filter leaf tests at 2, 6, and 10 minutes cycle time and began various solids analyses.

Day 2 -- Completed stirred and unstirred thickening tests, completed filter leaf tests, and various solid analyses for the various thickening and filtration tests. Collected sludge sample from the 1/2 inch tap sampling point near the reactor clarifier. Conducted gravity settling, filter leaf tests, and various solids analyses.

Day 3 -- Two hours to complete solids analyses and pack equipment.

It was not possible to complete all of the sludge testing at the site in this limited period. Sludge samples were brought back to the Taft Center for further work, **including chemical analyses.**

Specific Resistance Measurements. All specific resistance measurements were made without sludge conditioning. Specific resistances were determined at 10, 15, 20, and 25 inches (mercury) vacuum.

Filter Leaf Tests. All filter leaf tests were conducted without sludge conditioning. Filter leaf tests were conducted at least in duplicate for 2, 4, 6, 8, and 10 minute cycle times. **Form time was 1/3 of cycle time.**

Thickening Tests. Thickening tests were carried out following Eimco's test procedure which utilizes a 2-liter graduated cylinder equipped with a slow speed stirrer. Gravity thickening tests also were conducted in 50-gallon plastic drums. At first, reading of sludge and supernatant levels were taken every 5 to 10 minutes. However, it soon became evident that the lime sludges thickened very slowly. Thereafter, readings were taken on an infrequent basis and after overnight thickening.

RESULTS:

Sludge Quantity. It was not possible to make direct quantitative measurements of sludge quantity being discharged to the lagoon. However, the analyses of the wastewater entering and leaving the tertiary clarifier (before pH adjustment) shown in Table 3 can be used to estimate the sludge quantity being discharged to the lagoon, and the amount of active lime being used.

The calculation of lime sludge production and lime dose are presented in Table 4. Calculated sludge production and lime dose are as follows:

Sludge production:	409 mg/l
Total quicklime dose:	190 mg/l

The calculations from which these figures were derived are based on analytical data. No tenuous assumptions were needed.

The calculated value of sludge production can be compared with the values calculated from the measured sludge concentration and estimated volume. The suspended solids from the fresh lime sludge was measured to be 8.4 percent (see Table 5). Lime sludge blowdown is about 150 gallons for each two hours of tertiary treatment. Over a 24-hour period this is equivalent to 150 x 12 = 1800 gallons/day sludge blowdown. The average wastewater flow estimated is 311,000 GPD. The 8.4% sludge concentration can now be converted to a total wastewater flow basis:

$$84{,}000 \text{ mg/l} \times \frac{1800}{311000} = 486 \text{ mg/l}$$

This figure is in reasonable agreement with the value of 409 mg/l calculated from the wastewater analyses.

With regard to lime feed, the designer apparently planned to set the lime feeder at a steady rate which would give 150 mg/1 when the wastewater flow was at 0.4 MGD. Adjusting for the wastewater flow rate during our visit:

$$150 \times 0.4/0.3 = 193 \text{ mg/1}$$

This checks very well with the value calculated from wastewater analyses (190 mg/1). However, at the time of our visit, the lime feeder was operating on manual control, with the dose being controlled to maintain a pH of 10 in the clarifier. Thus the above calculation only shows that the calculated dose and measured input dose probably corresponded reasonably well.

Sludge Thickening. Neither the aged nor fresh lime sludges thickened to any significant amount. For both sludges, the reduction in original sludge volume was less than 10% under gravity settling without stirring after 14 hours (see Table 5 for original solids concentrations). The stirred thickening test on the aged lime produced a sludge volume reduction of about 16% (2,000 ml to 1680 ml) after 14 hours stirring at 2 rpm.

Despite the slow rate of thickening, lagoon sludge concentration was 17.5% (see Table 5). Since the sample point was very close to the pipeline discharge pump, this sludge could not have been more than a few days old. In view of the slow thickening rate observed, the twofold increase over the concentration of the sludge leaving the clarifier (8.4%--see Table 5) is surprisingly large.

Filter Leaf Tests. The results of the filter leaf tests are presented in detail in Table 6. Results are presented graphically in Figures 1 and 2, where filter yield is plotted against total cycle time. Figure 2, which is for the fresh lime sludge taken at the 1/2 inch tap, shows what is evidently a high yield. There is substantial scatter but the data are reasonably well represented by a line of -0.5 slope on the logarithmic plot. This slope is in accordance with the theoretical expectation that yield is proportional to cycle time raised to the - 0.5 power.

Loading is related to yield by the following equation:

$L = Y \cdot \theta$

where L = loading on filter cloth (lb/ft^2)

L = yield (lb/ft^{2}hr)

θ = cycle time (hour)

Curves for loading vs. cycle time, constructed from the yield curves, are also shown in Figures 1 and 2. It is expedient to check whether the loading corresponding to the yields are sufficiently high to permit the cake to be removed from the filter. Lime sludge can be removed from a rotary vacuum filter down to a cake thickness of about 1/8 inch; below this thickness cake release problems may be encountered. For a 30 percent solids cake with a specific gravity of about 1.4, this cake thickness corresponds to a dry solids loading of about 0.27 lb/ft^2.

Referring to Figure 2, it appears that cycle times below 2.9 minutes may be impractical because solids loading and therefore cake thickness are low. Maximum practical cake filter yield then is about 5.6 lb/ft^{2}hr.

Results for the sample of aged sludge, collected at the outlet from the pipeline, are shown in Figure 1. Filter yields are much lower than for fresh sludge. There is substantial scatter, but the data can still be represented by a line with a slope of - 0.5 on logarithmic coordinates. The loading vs. cycle time curve, drawn from the yield curve shows that adequate cake thickness (ca. 0.27 lb/ft^2) does not build up until the cycle time is approximately 10 minutes. Thus, the maximum filter yield for this sludge is about 1.6 lb/hr-ft^2.

The solids content of the sludge cake has been correlated following a procedure suggested by Eimco (4), in which solids content is plotted as a function of the ratio of drying time to loading. Loading data is presented in Table 6. Since immersion is one-third of cycle time, drying time is two-thirds of cycle time.

The correlation is presented graphically in Figure 3. The correlation is not outstanding, but does show a clear difference between the fresh and aged sludge samples. The fresh lime sludge cake solids are about 32-33%, whereas the aged lime sludge solids are about 27-28%.

Specific Resistance. Only one specific resistance measurement, at 15 in. Hg, was determined at the site at Butler. The remaining specific resistance determinations, measured at 10, 20, and 25 in. Hg vacuum, were carried out at the Taft Center 7 to 10 days later. During this time interval, the pH of the lime sludges decreased 1.5 units. Solids concentration in the aged lime sludge increased from 11.9% to 14.4% and from 8.4% to 12.9% in the fresh lime sludge.

The effect of aging in the pipeline to the lagoon, noted earlier on the filter leaf studies, is expected to be small since now all of the samples were aged. The data which are presented in Table 8 show some anomalies. The "aged" sample from the end of the discharge pipe shows a lower specific resistance at 20 and 25 inches (Hg) of vacuum than the "fresh" sample, but solids content after 12 minutes on the Buchner filter was much lower. No explanation is offered for these differences. The data serves the purpose of approximately determining the specific resistance of these lime sludges.

Sludge Constituents. Table 8 shows the constituents in the three lime sludge samples. There appear to be only minor changes in the ratio of constituents in the sludges. Data are not sufficient to indicate whether any significant differences exist between the "fresh" sludge and the sludge from the lagoon.

COMMENTS ON PLANT DESIGN AND OPERATION:

The Butler treatment plant is only sparingly instrumented. Thus, combined sludge flow measurement to the digesters, quantity of digester supernatant recycled, and quantity of digester sludge discharged are not available. Combined sludge is drawn from the primary settlers twice daily. The volume of combined sludge sent to the digester is estimated at 1% of the total plant flow.

Problems have been encountered in the lime feeding system in the tertiary process. The slaked lime is transferred by means of a centrifugal pump through a two-inch line which is reduced to one inch at the pump discharge. There are several right angle bends in the line. Much difficulty has been encountered with plugging. The line may be cleared either by injecting high pressure water into it or by manually disassembling and cleaning it.

The plant is attended part-time and only on weekdays (staff comprises a plant superintendent, chemist-operator, and an operator). If plugging occurs during unattended periods, the slaker overflows. Slaked lime is wasted to the floor drain which is connected to the head end of the treatment plant.

Problems with the lime feeding system have been singled out because this is a troublesome and high maintenance part of all lime treatment plants. I recommend that an important place be given to design of lime feeding systems in technology transfer seminars and publications.

Another factor which caused operations unreliability was created by the hard water at Butler. Originally the tertiary effluent was to be used for lime slaking. However, the pH 10 lime treatment reduces the hardness by only 25 percent. When the tertiary effluent was used in the lime slaker, chemical precipitation occurred and caused clogging in the line conducting slaked lime to the reactor-clarifier. This problem was solved by installing two demineralizers to continually supply softened water (one demineralizer onstream during regeneration of the other unit) for lime slaking.

LITERATURE CITED

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2. Bennett, S. M., and Bishop, D. F., "Solids Handling and Reuse of Lime Sludge," Project 11010 FYM, to be published in U.S. EPA series.

3. Mulbarger, M. C., Grossman, E. III, Dean, R. B., and Grant, O. L., "Lime Clarification, Recovery, Reuse, and Sludge Dewatering Characteristics," JQPCF, 41, No. 12, 2070-85 (1969).

4. Eimco Corp., "Bench Scale Testing Procedures for Thickening, Chemical Conditioning, Filtration," Sept. 1969.

TABLE 1: CHEMICAL PARAMETERS FOR WELL WATER, BUTLER, INDIANA
(in mg/l unless otherwise stated)

Constituents	Well No. 1	Well No. 2
pH (pH units)	7.6	7.6
Hardness (as $CaCO_3$)	300	294
Calcium	74	70
Magnesium	28	28
Sodium	15	15
Potassium	2	2
Iron	0.2	1.9
Manganese	< 0.02	< 0.02
Arsenic	< 0.01	--
Methyl Orange Alkalinity (as $CaCO_3$)	320	308
Chloride	1	1
Sulfate	11	11
Phosphate (as PO_4)	0.4	0.1
Fluoride	0.9	0.9
Nitrate-Nitrogen	0.4	0.3

TABLE 2

OVERALL PLANT OPERATION AT BUTLER, INDIANA
NOVEMBER and DECEMBER 1972

	November	December
Raw Wastewater		
BOD_5 (mg/l)	96	105
pH	7.8	7.9
Primary Effluent		
BOD_5 (mg/l)	65	61
BOD reduction (%)	32	42
pH	--	--
Final Effluent		
BOD_5	13	21
BOD reduction (%)	86	80
pH	8.4	8.6
Additional Information		
Trickling Filter Loading Rate (lbs BOD/1000 ft^3-day)	69	67
Average Flow (MGD)	0.41	0.44
Secondary Effluent D.O. (mg/l)	9.4	11.1
Residual Chlorine (mg/l)	0.3	0.5

TABLE 3: ANALYSES OF WATER AND WASTEWATER THROUGH TREATMENT SEQUENCE AT BUTLER, INDIANA

(mg/l unless otherwise indicated)

Constituent	Water (From Laboratory Tap)	Raw Wastewater	Secondary effluent	Tertiary effluent (Before pH adjustment)	Tertiary effluent (After pH adjustment)
Total COD	14.2	193	70.1	51.3	43.5
Total TOC	1.8	48	17.2	12.6	11.8
Total P	< 0.1	3.5	3.0	0.7	0.7
Suspended Solids	< 1.0	126	11.6	14.8	3.6
pH (as pH units)	7.6	7.6	7.8	9.5	8.9
Alkalinity (as $CaCO_3$)	310	365	338	160	132
Total Hardness (as $CaCO_3$)	270	322	361	272	219
Calcium	62	83	91	66	45
Magnesium	28	28	30	26	26
Total Dissolved Solids	338	608	944 (1)	582	614
Sodium	16.0	86	142	122	122
Potassium	2.5	17.0	9.5	6.5	9.3
Iron	0.6	0.5	0.2	0.7	0.5
Manganese	0.1	0.1	0.1	< 0.1	< 0.1
Sulfate	10.0	68.0	64.0	63.0	100.0
Total Kjeldahl Nitrogen	0.5	21.7	10.5	7.6	7.3
Ammonia-Nitrogen	0.5	16.6	9.2	4.1	5.1
Nitrite-Nitrogen	< 0.1	< 0.1	0.6	0.3	0.3
Nitrate-Nitrogen	< 0.1	< 0.1	1.8	3.0	2.6
Chloride	5.0	90.0 (2)	242.0 (2)	205.0 (2)	208.0 (2)
Aluminum	0.5	0.9	0.4	< 0.1	0.5
Zinc	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Copper	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Lead	< 0.1	0.5	0.4	0.1	< 0.1

Notes: (1) Sample contained oils and grease.

(2) Chloride content is exceptionally high, because salt was used on the roads just the day before our field test. Butler has combined sewers so the salt ends up in the wastewater. The concentration of Cl in the raw wastewater appears to be in error.

TABLE 4: ESTIMATE OF LIME SLUDGE PRODUCED AND ACTIVE LIME DOSAGE AT BUTLER, INDIANA
(January 23 and January 24, 1973)

Assumptions:

(a) Average wastewater flow to tertiary
346,000 gallons/day
(less) 35,000 gallons/day sludge to digester
311,000 gallons/day w.w. to tertiary

(b) Δ SS (mg/l) from Table 3--sec-tertiary is 8 mg/l.

(c) Δ P (mg/l) from Table 3--sec-tertiary is 2.3 mg/l.

(d) $FeCl_3$ dose rate -- 6 mg/l based on 0.4 MGD flow. Adjusted for 0.311 MGD flow; $FeCl_3$ dose rate 8 mg/l, as ferric iron approximately 2.8 mg/l.

Δ Fe = sec-tertiary dose = 0.2 + 2.8 - 0.7 = 2.3 mg/l

(e) Δ HCO_3^- (total alkalinity) -- expressed as $CaCO_3$ sec-tertiary = 178 mg/l.

(f) Δ Mg, sec-tertiary = 4.5 mg/l.

(g) Δ Ca, sec-tertiary = 25 mg/l.

(h) The actual lime dosage is unknown but target level is 150 mg/l CaO at 0.4 MGD flow.

Calculation:

(1) $CaCO_3$ formed--

Alkalinity in secondary effluent at pH 7.8 is essentially all HCO_3^-. Loss of HCO_3^- is the only source of $CaCO_3$.

$$Ca^{++} + HCO_3^- \longrightarrow CaCO_3 + H^+$$

$$\frac{178}{50} = 3.56 \text{ mg - equivalent/l of } HCO_3^-$$

$$\text{and } 3.56 \ \frac{\text{mg-equivalent}}{\text{liter}} \times 100 \ \left(\begin{array}{l}\text{Molecular}\\ \text{wgt of}\\ CaCO_3\end{array}\right) = \frac{356 \text{ mg/l}}{\text{as } CaCO_3}$$

TABLE 4 (Continued)

(2) Assume P precipitates as calcium hydroxyapatite ($Ca_5OH(PO_4)_3$

Molecular weight of $Ca_5OH(PO_4)_3 = 502$

$\% \text{ P} = \frac{31 \times 3}{502} = \frac{93}{502}$

P as $Ca_5OH(PO_4)_3 = 2.3 \times \frac{502}{93} =$ 12.4 mg/l as calcium hydroxyapatite

(3) $Mg(OH)_2$ produced

Δ Mg = 4 mg/l

$4 \times \frac{58.3}{24.3} = \underline{9.6 \text{ mg/l as } Mg(OH)_2}$

(4) $Fe(OH)_3$ produced

Δ Fe = 2.3 mg/l

$2.3 \times \frac{106.85}{55.85} =$ 4.4 mg/l as $Fe(OH)_3$

(5) Calcium addition from Active lime dosage in the lime sludge

(a) Total calcium in lime sludge

142 mg/l from $CaCO_3$ formation

($356 \text{ mg/l} \times \frac{40}{100} = 142$ mg/l -- see 1)

5 mg/l from calcium hydroxyapatite ($12.4 \text{ mg/l} \times \frac{200}{503} = 5$ mg/l--see 2)

Total lime input 147 mg/l as calcium

(b) calcium precipitated from wastewater

From Table 3 - 91 mg/l secondary
-66 mg/l tertiary
25 mg/l calcium precipitated

(c) calcium added

Amount of calcium added from active lime dosage is

147 - 25 = 122 mg/l as calcium

$122 \times \frac{56}{40} \cong$ **171 mg/l as CaO**

TABLE 4 (Continued)

(d) lime dose

Assume that total lime contains 10% inerts

171/0.90 = 190 mg/l total lime dose

and 190 x 0.1 = 19 mg/l inerts in lime dose

(6) Total sludge quantity

$CaCO_3$	356 mg/l
$Ca_5OH(PO_4)_3$	12.4 mg/l
$Mg(OH)_2$	9.6 mg/l
$Fe(OH)_3$	4.4 mg/l
Inerts in lime	19.0 mg/l
Suspended solids	8.0 mg/l
Total	409.4 mg/l

TABLE 5: TOTAL & SUSPENDED SOLIDS AND PERCENT VOLATILE SOLIDS

Lime Sludge Sample	Total Solids (mg/1 & %)	Suspended Solids (mg/1 & %)	% Total Volatile Solids	% Volatile Suspended Solids
From one-half inch top Control Room (1-24-73)	94,000 9.5%	84,000 8.4%	9.2	8.0
Exit of 3,000 foot 8 inch diameter pipe at Sludge Lagoon	--	119,000 11.9%	--	5.9
Sludge Lagoon	--	175,000 17.5%	--	8.2

TABLE 6: SUMMARY DATA FILTER LEAF TESTS

Total Cycle Time (seconds)	% Solids (Duplicates)	Filter Yield (lb/hr--sq.ft.) (Duplicates)	Filter Loading (lb/sq.ft.) (Duplicates)
(a) 1-23-73 -- Aged Lime Sludge Sample (from end of 3,000 foot discharge pipe) Suspended solids concentration - 11.9%			
120	28.2, 19.1	4.4, 4.4	0.15, 0.15
240	27.0, 27.9	1.7, 1.9	0.11, 0.13
360	28.3, 28.9	1.9, 2.1	0.19, 0.21
480	26.5, 36.2	1.9, 1.6	0.25, 0.21
600	33.2, 27.6	2.0, 1.6	0.33, 0.27
(b) 1-24-73 -- Fresh Lime Sludge (from 1/2 inch tap) Suspended solids concentration - 8.4%)			
120	33.7, -	4.4, -	0.15, 0.15
240	32.4, 29.2	4.7, 5.4	0.32, 0.36
360	32.8, 35.6	4.6, 3.4	0.46, 0.34
480	32.1, 31.4	3.5, 3.3	0.47, 0.45
600	29.3, 32.4	3.3, 2.9	0.56, 0.48

Notes: (1) Form Cycle - 1/3 of the total cycle time.

(2) Filter Leaf Area - 4" diameter, 0.0873 sq.ft.

(3) 808 Filter Leaf Media

TABLE 7: SPECIFIC RESISTANCE OF BUTLER LIME SLUDGES

Sludge Sample	Vacuum Applied (in. Hg)	Specific Resistance ($cm/g \times 10^{-11}$)	& Cake Solids *
Sludge from end of discharge pipe (1-23-73) ("aged" sample)	10	1.37	26
	20	0.47	34.5
	25	0.34	34.5
Sludge from 1/2-inch sample tap (1-24-73) ("fresh" sample)	15	1.74**	32
	10	1.25	32
	20	0.82	58
	25	1.03	56

* % cake solids is solids content at the termination of the test (12 minutes after 100 ml of sludge is charged to the filter)

** Specific resistance was determined on the day of the test. All others were determined 7-10 days later.

TABLE 8: COMPOSITION OF LIME SLUDGES (BUTLER, INDIANA)

Element	Sludge from 1/2-inch tap	Sludge from End of Pipeline	Sludge from Lagoon
	..................Concentration (mg/g)..................		
Ca	338	358	310
Mg	8.8	10.6	9.0
P	4.6	10.0	5.6
Na	0.8	3.4	0.8
K	1.2	< 0.1	0.4
Al	5.0	1.3	6.4
Fe	7.8	18.2	14.0
Mn	0.3	0.2	0.4
Cu	< 0.1	< 0.1	< 0.1
Zn	0.2	< 0.1	0.2
Pb	0.5	0.5	0.4
TKN	4	3	5
NH_3	0.4	0.1	0.4
COD	143	74	151

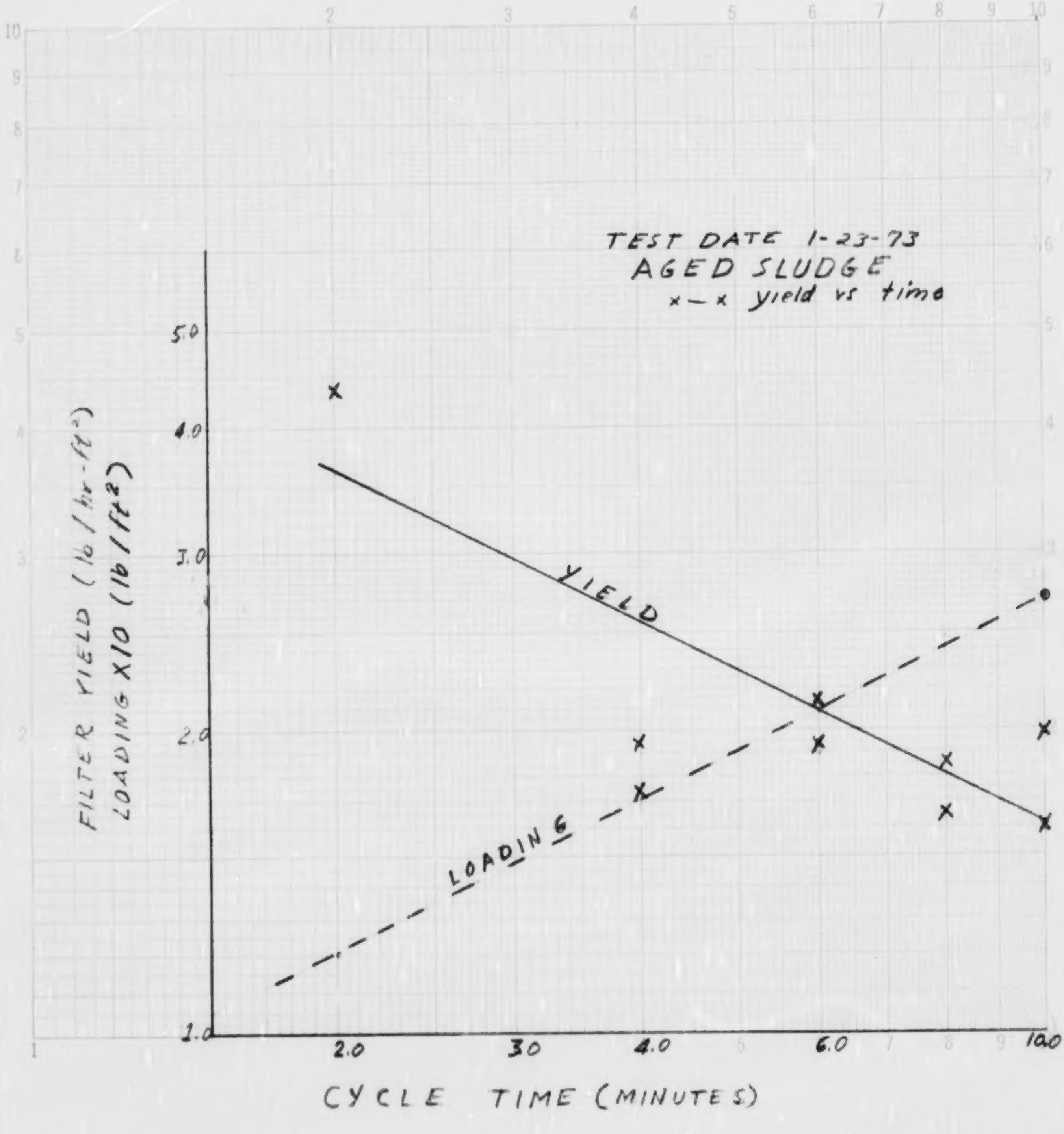

FIGURE 1 : FILTER LEAF TESTS (BUTLER, IND.)

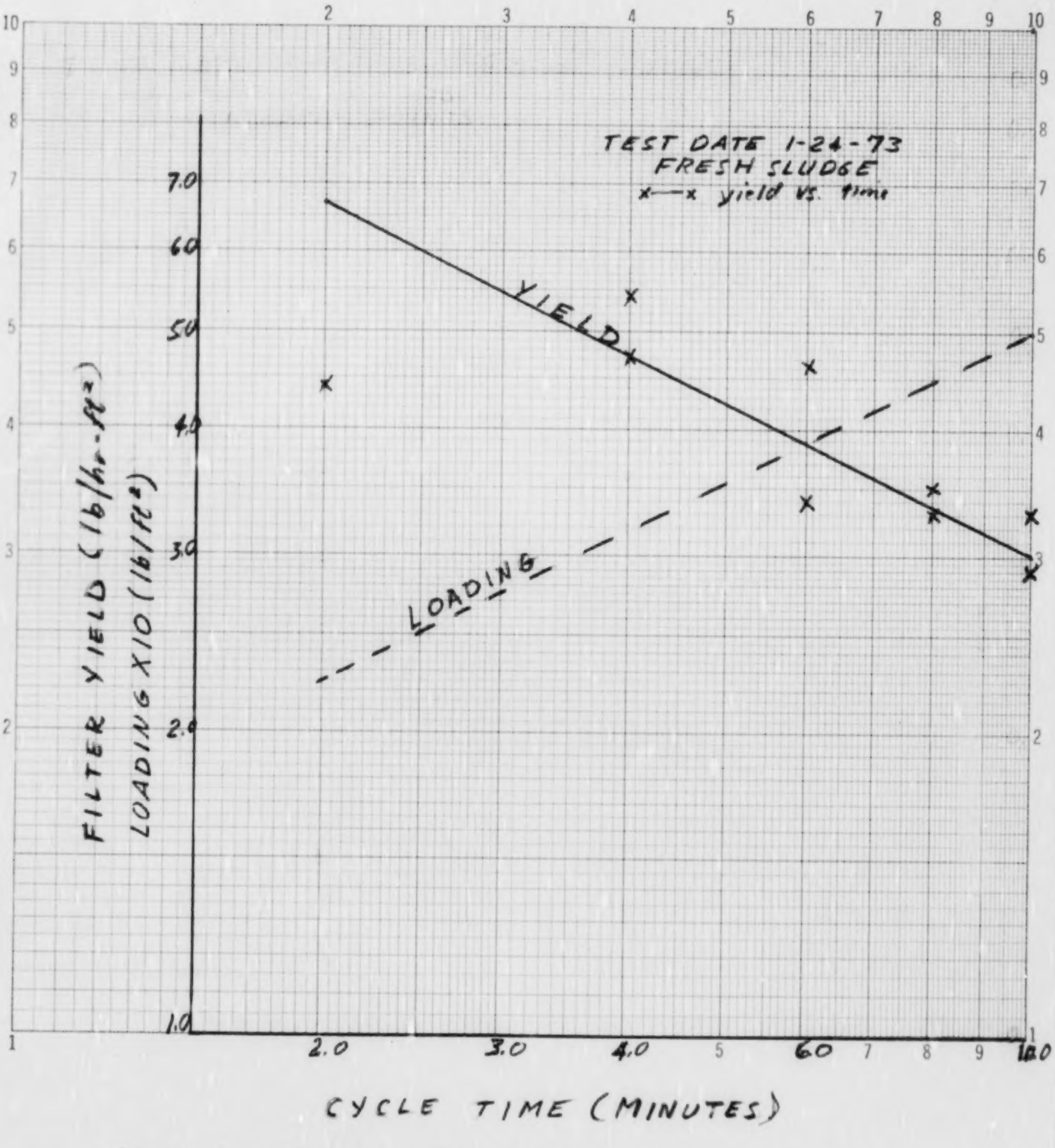

FIG. 2 : FILTER LEAF TESTS (BUTLER, IND.)

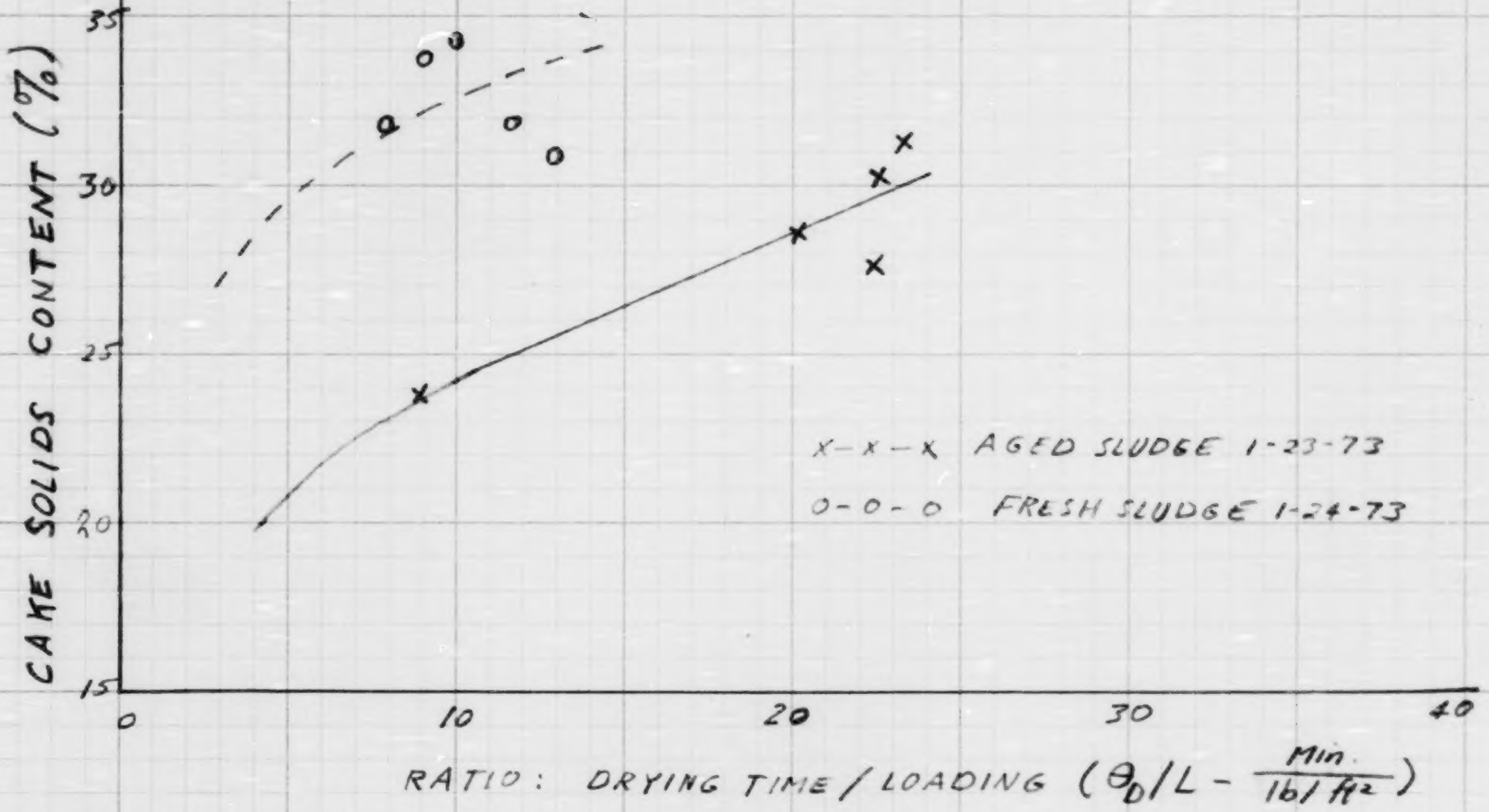

FIG. 3: CORRELATION OF FILTER CAKE SOLIDS CONTENT WITH FILTER OPERATING VARIABLES

APPENDIX H

Sludge Information Summary No. 6

Cleveland Westerly

Type of Sludge

Primary physical-chemical treatment sludges, produced by addition of either ferric chloride or lime to raw sewage.

Source of Information

Preliminary version of "Westerly Advanced Wastewater Treatment Facility: Process Development and Engineering Design," preliminary draft dated 16 September 1971, prepared for

The City of Cleveland
Department of Public Utilities
Division of Water Pollution Control.

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Date Prepared

October 2, 1973 45 pp.

Objective of Summary

This and similar summaries extract information on sludges from reports of investigations of wastewater treatment. Such reports are sometimes of limited availability, are often lengthy, and their primary objectives are often not related to sludge disposal. The "Sludge Information Summary" condenses the information on sludges into a few pages.

The summary writer has attempted to use critical judgement. Wherever possible, results are related to other studies, and judgements are made regarding the value of the results. Such interjection of the summary writer's opinions are pointed out clearly in the summary.

In many cases, it has been convenient to quote the report author verbatim. These cases are identified by quotation marks. Except when denoted by an "S" following the number, tables and figures are those of the original report author.

Introduction

The report on the Cleveland Westerly plant is actually two nearly independent reports. The first report, prepared by Zurn Environmental Engineers, describes a design for a planned physical-chemical plant on the site of Cleveland's Westerly plant. The second report, by Battelle-Northwest, is attached as an appendix to this report. It describes the laboratory and pilot plant work which established the data base for the plant design. This Sludge Summary addresses itself only to the Battelle-Northwest report.

Laboratory and pilot plant investigations were carried out by Battelle-Northwest. Only a limited amount of information on sludges was obtained during the bench-scale laboratory experiments.

A substantial amount of information on the dewaterability of lime*-primary sludges**, using a vacuum filter and a solid bowl centrifuge, was obtained during the pilot plant investigation. A small amount of centrifuge data was collected for ferric chloride-primary sludges.

EXPERIMENTAL SYSTEM

The pilot plant flow sheet is presented in Figure 39. Maximum capacity was about 80 gpm. Two types of clarification systems were studied: a reactor-clarifier in which flocculation took place within the clarifier, and a flocculator-clarifier which was preceded by a separate flocculator. The flocculator-clarifier was operated as a conventional settling basin. Virtually all of the sludges studied in detail were produced using the flocculator-clarifier preceded by the separate flocculator.

Sludges leaving the clarifier were collected in a storage tank and then dewatered on either a vacuum filter or a solid-bowl centrifuge. Centrates and filtrates were returned to the pilot plant influent stream. The wastewater leaving the clarifier was recarbonated during runs with lime. At pH 10.5, where most of the sludge data in the report were collected, there was virtually no sludge deposition in the recarbonation tank. The wastewater was filtered through a dual-media or a tri-media filter, passed through carbon columns for dissolved organic removal, and finally through Clinoptilolite columns for ammonia removal.

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* The term lime in this summary refers to slaked lime, $Ca(OH)_2$.

** A lime-primary sludge is sludge produced by adding lime just prior to the primary clarifier. Its chief components are primary sludge, a phosphate compound of calcium (chiefly hydroxyapatite) and calcium carbonate.

The purpose of the holding tank for sludge was to store sludge until enough accumulated for dewatering studies. It was not used as a thickener, Prior to and during dewatering runs, the sludge in the tank was mixed by air sparging.

The centrifuge used in the pilot plant was a Bird six-inch solid-bowl conveyor-type machine powered by a 5 HP motor. It could be driven at 5000 or 3500 rpm. An Eimco belt filter, three feet in diameter with a 1-foot face, was selected for the filtration studies. Filter media was nylon.

EXPERIMENTAL RESULTS

A. Pilot Plant Performance

The characteristics of the wastewater entering the Westerly plant are given in Table 5. This wastewater has a high industrial component.

Since the great bulk of the data were obtained with lime, only pilot plant performance during lime addition will be discussed. The plant operated satisfactorily at pH 10.5 during dry weather conditions. Lime dose as $Ca(OH)_2$ is estimated to be 150 mg/l. Under wet weather conditions, operation was not satisfactory at these pH levels, but performance was suitable when pH was increased to 11.5. Estimated lime dose ($Ca(OH)_2$) is 250 mg/l as $Ca(OH)_2$. Figure 59 gives the experimentally determined lime dose - pH relationship for all pH values.

Performance of the pilot plant during the operation with lime is summarized in Table 7. Removals of suspended solids were reasonable at all pH levels and clarifier loadings. Consequently, anomalous sludge dewatering properties due to wide variations in clarifier efficiency (with subsequent effect on sludge properties) are not expected.

B. Bench-Scale Data

"Laboratory data indicate that $FeCl_3$ coagulation produces considerably more sludge on a wet volume basis than does lime clarification. Following a two-hour settling period, iron sludge volumes were observed to be a factor of two greater than lime sludge volumes for the same quantity of sewage treated. Lime sludge volumes ranged from 0.42-1.3% of the volume treated and iron sludge volumes from 1.8 - 2.9%. Sludge volumes from the pickle liquor and lime studies ranged from 0.5%-1.1% for a pickle liquor dose of 10 mg Fe/l and lime dose of 30 mg/l. On a dry weight basis, 0.375 g/l of lime sludge was produced as opposed to 0.255 g/l of iron sludge or 1.5 times more lime sludge on a weight basis.

Sludge dewatering characteristics of the chemical sludges were studied by filtering 100 ml sludge samples through Whatman #2 filter paper at 60 inches of water vacuum. Results of these Buchner funnel dewatering tests are presented in Figures 36, 37, and 38. Dewatering rates for $FeCl_3$ and lime sludges do not appear to be substantially different."

In this writer's opinion, the report authors' last statement is misleading. On a unit volume basis, the filtration rates of the sludges were not much different. However, as the authors observe above, iron sludge volumes were generally twice as great as lime sludge volumes. Consequently, one may conclude that filtration surface area requirement will be twice as great for iron sludges as for lime sludges. Mass and volume of sludge per unit volume of wastewater treated and sludge density are necessary for proper interpretation of the Buchner funnel data. If solids content of the sludge and of the filter cake were presented, it would be possible to calculate the specific resistance to filtration of the sludges.

C. Centrifugation of Iron-Primary Sludges

Operating conditions for runs in which ferric chloride was added to the raw sewage just prior to clarification are presented in Table 3. Dewatering data are presented in Table 16.

"During the period of ferric chloride coagulation, sludge was withdrawn from the flocculator-clarifier at a rate equal to 1% of the plant flow rate. This clarifier sludge ranged from 2-3.6% solids and averaged 3% solids, 60% of which were volatile solids. In general, capture was poor without the use of polymer. Centrifuge performance seemed to improve as the influent sludge solids decreased. Sludge conditioning will probably be required for efficient dewatering of the iron sludge". The author also points out that iron sludge volumes were two to three times greater than lime sludge volumes.

This writer has calculated recoveries from the data in Table 16. The poor recoveries indicate that polymer conditioning will be needed. Contrary to the authors' comment above, lower solids content in the feed stream did not give higher recovery for the runs listed in the table.

D. Centrifugation of Lime-Primary Sludges

Dewatering data obtained with the centrifuge are presented in Table 14 for the lime-primary sludges. Clarifier operating pH is included in Table 14, and clarifier hydraulic loading rate has been added by this writer to the table. Lime dose may be estimated from Figure 59.

"Sludge withdrawal from the clarifier was reduced to 0.3 to 0.5 percent of the total flow during the lime clarification studies. This yields a sludge that is 6-14% solids at a clarifier pH of 10.5. No additional thickening before dewatering is necessary."

"Operation of the centrifuge at 5000 rpm without sludge conditioning produces a centrate containing 0.2-0.5 percent dry solids*, which corresponds to 50-80 percent solids capture. The centrifuged sludge ranges from 20-45 percent solids. At 3500 rpm the centrate contains about 0.2 percent dry solids* more and the cake contains one percent dry solids less than the centrate and cake at 5000 rpm, respectively.

Several polymers which are listed in Table 15 were investigated as sludge conditioners. It was found that Atlasep 2A2, Nopcofloc 940, Calgon WT 2900, Calgon WT 3000, and Polyfloc 1120 all significantly improved centrifuge capture at dosages of less than 2 lbs per ton dry solids. A 0.1 or 0.2% solution of Nopcofloc 940 was used in the major portion of the testing. No difference in centrifuge performance due to the different solution strengths was observed.

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* Examination of Table 14 shows that these values should each be multiplied by 10, giving 2-5%, and 2%.

At a centrifuge rotation speed of 5000 rpm, the resultant centrifugal force is 2120 gravities. Since this is beyond the centrifugal force applied by most production machines, the major protion of the work was conducted at 3500 rpm (1020 gravities). Some data at 5000 rpm were gathered for comparison purposes.

Polymer addition was required to attain good centrate quality. The polymer dose necessary to obtain 95% solids capture varied from about 1.2 to 1.7 lbs/ton dry solids at sludge flow rates of 2 and 4 gpm, respectively, and at a rotation speed of 3500 rpm. The required polymer dose increased rapidly at sludge flow rates greater than 4 gpm.

Solids capture was dependent on polymer dose. Figures 68 and 69 show that as polymer dose increases, initially the solids capture improves rapidly then asymptotically approaches 100% capture. At very high polymer dosages, however, the capture is observed to decline slightly.

At higher rotation speeds improvement was noted in both solids capture and cake solids content. At 5000 rpm the required polymer dose was 30 percent lower than at 3500 rpm for equal centrate quality. At 5000 rpm the cake solids ranged from about 20-30 percent dry solids and at 3500 rpm the solids content was 20-28 percent.

The dewatered sludge solids content is dependent on the solids capture in the centrifuge. Centrifuge runs at constant polymer dosage and varying sludge feed rate as well as runs at constant sludge feed rate and varying polymer dosage both indicated that dewatered sludge solids content decreased as solids capture increased. The solids content in these runs averaged about 26 percent at 70 percent capture and about 22 percent at 90 percent capture.

The sludge solids content of the centrifuge feed had little effect on the polymer requirements. Figures 70, 71, and 72 indicate that at a 2-4 gpm feed rate the cake solids content decreases with increasing feed sludge solids content. The general increase in cake solids with feed rate illustrated in Figures 70, 71, and 72 is believed to be due to the lower solids capture during the high feed rates runs.

The effect of pool depth was small. No net effect was observed in cake solids and only a slight increase in solids capture was observed when operating at a pool depth of 0.7 in. as compared to 0.5 in."

The authors observed that centrate (or filtrate) that was about 1 day old contained about 10 mg/1 of P, whereas a batch left for 4 days has P levels of 200 mg/1. At 90-95% solids capture, centrates (or filtrates) shows BOD's of 800-3200 mg/1 and COD's of 3,000 to 20,000 mg/1.

The valuable information contained in Table 14 has not been capitalized on completely by the report authors. For example, data collected on 2/19/71 are presented in Figure 70 S, and show that sludge cake solids increases as feed rate increases. Information on recovery is also contained in Table 14 and is plotted against feed rate in Figure 70 S. Recovery falls rapidly with increased feed rate of sludge. The higher solids content of the cake at higher feed rates is evidently due to an excessive loss of fines to the centrate.

The authors state that most of the runs were made at 3500 rpm. It is not clear from the table which runs were at 3500 rpm and which were at 5000 rpm. This writer has transferred information on rotational speeds given on the figures back to the table.

The writer is not convinced of the validity of the evidence (Figures 70, 71, 72) that lower feed solids results in greater cake solids. Firstly, the comparison should probably be made at equivalent solids mass flow rather than liquid flow, and secondly, the sludges were collected on different days.

E. Continuous Vacuum Filtration of Lime-Primary Sludges

Experimental vacuum filtration data obtained with lime-primary sludges are presented in Table 15. This writer has made some additions to this table. Clarifier loading rates have been included (taken from Table 4 - not included in this summary) to indicate that clarifier loading rates were reasonable. The authors neglected to present the filter rotational speed in the table. This information was obtained from Figures 73-83 where solids capture, cake solids, and filter yield were plotted against rotational speed on arithmetic coordinates. Percent immersion was calculated from the diameter of the filter and the immersion depths indicated in Table 15. Cycle time also presented in Table 15, is merely the inverse of filter speed. Drying time, which is used in correlating the data (see below), equals (1.0 - fraction immersion) (cycle time). Loading, also used to correlate the data, is the product of filtering rate and cycle time.

The authors' Figures 73-83 have not been reproduced in this summary. Instead, the data have been replotted in what appears to this writer to be a more customary manner. The letters on these diagrams indicate a particular sludge. For example, the three curves labelled A merely present the relationship between different variables for the same sludge.

In Figures 73 S and 74 S, filter yield has been plotted against cycle time on logarithmic coordinates for the four batches of sludge extensively studied by the authors. Ordinarily, filter yield versus cycle time produces a straight line with a slope of -1/2 on logarithmic coordinates.

The effect of polymer on yield is very marked for Sludge A (14.1% solids sludge in Fig. 73 S). Rate approximately doubles with polymer addition. It should be noted the results with polymer are highly unusual and probably represent a non-steady state condition. The absolute value of the slope of this curve is greater than 1. This means that as the time the filter medium is immersed in the sludge is reduced, the thickness of the layer of sludge solids which builds up increases.

On each yield vs. cycle time diagram, there is drawn a line of constant dry solids loading*. Dry solids loading is approximately proportional to thickness of the sludge layer on the filter medium. The loading of 0.23 lb/ft^2 used for these figures corresponds to a wet cake thickness of 1/8-inch. It is unusual to be able to successfully operate a vacuum filter at lower cake thicknesses than this. Consequently, where the experimental filter yield falls below the yield indicated by the yield vs. cycle time line at L=0.23 $lb.ft^{-2}$, this is a dubious operating condition.

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* Dry solids loading, yield, and cycle time are related by the following equation:

$Y = L/\theta_c$

where L = dry solids loading (lb ft^{-2}) as the filter system emerges from the sludge

θ_c = cycle time (hr /complete revolution)

Y = yield (or filtration rate - $\text{lb ft}^{-2}\text{hr}^{-1}$)

If a value of L is chosen, a line of constant L may be calculated merely by choosing values of θ_c and calculating Y.

Referring again to Sludge A in Fig. 73 S, it is seen that the sludge with no polymer starts to form too thin a cake when cycle time gets below 3.0 minutes. The maximum yield then is seen to be about 4.5 $lb.hr^{-1}ft^{-2}$. Sludge D in Figure 74 S shows a similar problem for the low polymer dose. Minimum cycle time is about 2.0 minutes and maximum yield is about 7.0 $lb.hr^{-1}ft^{-2}$. The authors note that cake release problems were encountered at lower cycle times. However, they attribute the difficulty to high moisture content.

For the other sludges in Figures 73 S and 74 S, operation will probably not be limited by too thin a cake but by the hydraulics of water removal. Cycle times less than 1.0 minute are generally thought to be impractical. The reason usually given is that at high rotational speeds, there is insufficient time for the water removed from the sludge and cake to drain out of the filter segment and associated piping.

Moisture content of cake is presented in Figure 75 S as a function of the correlating factor θ_D/L. This factor, which is the drying time per unit of dry cake loading, is an intuitively reasonable way of correlating solids content, and is recommended in Eimco publications. Correlation for each of the different sludges is satisfactory. The use of different concentrations of polymer does not affect the correlation. This is a different conclusion than the one drawn by the report authors. The discrepancy is attributable to the method of correlation - they plotted solids content against filter speed. At a given speed, the higher dose of polymer gave a higher yield. Because there was less drying time/unit loading of sludge, the cake was wetter.

Recovery has been plotted against loading in Figure 76 S. Since the filter surface becomes more impervious to solids as cake builds up, it is logical to expect that loading would be a suitable correlating factor. The correlation is seen to be reasonably good in Figure 76 S. If there is an effect of polymer dose on recovery, it is not large. This is also contrary to the authors' conclusions. They showed that recovery vs. filter speed curves were at higher recovery levels for higher polymer doses. The reason for the apparently higher recovery is clear - cake thickness was greater at a given speed for the higher polymer dose.

It is interesting to note that the four sludges tested showed substantial differences in yield, moisture content, and solids recovery. This is to be expected since they were collected on four separate days over a 25-day period.

E. Incineration of Lime-Primary Sludges

Samples of lime sludge were collected at pH 10.5 and pH 11.5 and calcined in a pilot-scale multiple hearth calciner by BSP Corporation.

Calcination could be carried out at satisfactory rates. Details of the calcination test are included in an appendix to the Battelle-Northwest report (not included in this summary).

The authors conclude that unless the calcined ash is classified to enrich it in CaO, the costs of the extra solids-handling equipment will make calcination uneconomical.

Analytical data obtained in the BSP test have been used to calculate mass of sludge and calcined solids relative to a given quantity of volatile sludge solids (Table 17 S). The much larger quantity of sludge and residue which result from operation at pH 11.5 is evident.

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TABLE 5

Summary of Wastewater Characteristics at Westerly

Monthly Average	Alkalinity @ $CaCO_3$ (mg/1)	Chloride (mg/1)	Iron (mg/1)	COD (mg/1)	BOD (mg/1)	TS (mg/1)	TVS (mg/1)	SS (mg/1)	Total P (mg/1)	NH_3 (mg/1)	Sulfate (mg/1)	Total N (mg/1)
September, 1970	160	90	6.4	501	214	746	280	206	6.2	9.1	98	23
October, 1970	158	86	3.1	408	222	687	271	178	5.2	9.1	82	23
November, 1970	177	105	4.1	655	264	811	313	224	5.4	10.5	102	26
December, 1970	166	144	4.5	510	235	831	296	190	5.0	9.2	137	22
January, 1971	173	166	3.4	566	243	904	321	206	5.4	9.3	133	25
February, 1971	131	269	3.7	481	210	1026	275	233	4.4	5.7	83	18
March, 1971	166	228	4.3	542	251	1071	322	215	5.3	8.6	110	24
Average Pilot Plant Operation	162	155	4.2	523	235	867	297	207	5.4	8.8	106	23
Minimum Day, 1970	100	60	1.0	71	30	438	76	22	0.6	4.2	34	9.0
Average for 1970	167	134	5.3	564	206	826	--	211	6.4	---	---	---
Maximum Day, 1970	232	800	26.4	1984	680	1884	604	578	17.4	17.9	192	45

TABLE 7

Average Pilot Plant Performance at Various pH Values and Flocculator-Clarifier Overflow Rates During Lime Clarification Operating Period

	Total P (mg/1)	Cumulative Removal %	B O D (mg/1)	Cumulative Removal (%)	C O D (mg/1)	Cumulative Removal (%)	S S (mg/1)	Cumulative Removal (%)	Turbidity (JTU)	Cumulative Removal (%)
pH 10 $660\ gpd/ft^2$										
Raw	4.7	-	251	-	384	-	219	-	95	-
Clar Eff	-	-	-	-	-	-	46	79	27	72
Filter Eff	-	-	-	-	141	63	17	92	15	84
Carbon Eff	0.85	82	23	91	40	90	14	94	8	92
pH 10 $1020\ gpd/ft^2$										
Raw	5.5	-	227	-	329	-	180	-	90	-
Clar Eff	1.3	76.4	155	31.7	177	46.2	37	79.4	27	70.0
Filter Eff	0.9	83.6	80	64.8	151	54.1	14	92.2	12	83.8
Carbon Eff	0.65	88.2	32	85.9	56	83.0	10	94.4	7	92.2
pH 10.5 $1020\ gpd/ft^2$										
Raw	4.8	-	241	-	495	-	228	-	94	-
Clar Eff	1.5	69.0	135	44.0	207	58.2	73	68.0	29	69.3
Filter Eff	.9	81.0	91	62.3	150	69.6	33	85.5	15	84.0
Carbon Eff	.8	83.4	49	79.8	73	85.1	23	89.9	11	88.4
pH 10.5 $1180\ gpd/ft^2$										
Raw	3.9	-	-	-	516	-	177	-	106	-
Clar Eff	1.4	64.1	185	-	208	59.7	95	46.3	20	81.1
Filter Eff	0.9	76.9	78	-	150	70.9	28	84.2	13	87.7
Carbon Eff	0.5	87.2	20	-	26	95.0	14	92.1	6	94.3
pH 10.5 $1310\ gpd/ft^2$										
Raw	6.0	--	246	--	482	--	191	--	86	--
Clar Eff	1.8	70.0	103	58.2	217	55.1	79	58.8	23	73.4
Filter Eff	1.0	83.3	99	59.9	207	57.1	30	84.4	5	94.1
Carbon Eff	1.0	83.3	53	78.5	109	77.4	29	85.0	4	95.4

TABLE 7 (Cont.)

Average Pilot Plant Performance at Various pH Values and Flocculator-Clarifier Overflow Rates During Lime Clarification Operating Period

	Total P (mg/1)	Cumulative Removal (%)	B O D (mg/1)	Cumulative Removal (%)	C O D (mg/1)	Cumulative Removal (%)	S S (mg/1)	Cumulative Removal (%)	Turbidity (JTU)	Cumulative Removal (%)
pH 11.0 1020 gpd/ft^2										
Raw	7.0	-	270	-	707	-	276	-	50	-
Clar Eff	0.95	86.4	175	35.2	161	77.2	104	62.3	8	84.0
Filter Eff	0.75	89.3	104	61.5	110	84.4	72	73.9	4.5	91.0
Carbon Eff	0.45	93.6	43	84.1	39	94.5	46	83.3	2	96.0
pH 11.8 1020 gpd/ft^2										
Raw	4.8	-	132	-	524	-	176	-	58	-
Clar Eff	-	-	-	-	149	71.6	23	86.9	5	91.4
Filter Eff	-	-	-	-	122	76.7	11	93.8	3	94.8
Carbon Eff	0.2	95.8	26	80.3	50	90.5	6	96.6	2	96.6
pH 12.2 1020 gpd/ft^2										
Raw	5.75	-	231	-	547	-	112	-	75	-
Clar Eff	-	-	74	68.0	129	76.4	10	91.1	5	93.3
Filter Eff	0.1	98.3	90	61.0	123	77.5	20	82.1	2.5	96.6
Carbon Eff	0.1	98.3	44	81.0	46	91.2	6	94.6	2	97.3

TABLE 3

Operating Parameters During FeCl$_3$ Runs

Date	Clarifier Flow Rate (gpm)	Clarifier Hydraulic Loading (gpd/ft^2)	Fe^{+++} Dose (mg/l)	Polymer Dose (mg/l)	Filter Flow Rate (gpm)	Filter Hydraulic Loading (gpm/ft^2)	Carbon Flow Rate (gpm)	Pre-Filter Polymer Dose (mg/l)
Sept. 16, 1970	31.5	410	20	1.0	30	3.1	20	0
17	31.3	410	20	0.5	30	3.1	20	0
18	31.3	410	20	0.5	30	3.1	20	0
21	50	660	20	0.5	44	4.5	20	0
22	50	660	20	0.5	40	4.1	20	0
23	50	660	20	1.0	40	4.1	20	0.5
24	79	660	20	1.0	40	4.1	20	0.5
25	79	1040	20	0.8	40	4.1	20	0.5
28	79	1040	20	0.5	40	4.1	20	0.5
29	79	1040	20	1.0	40	4.1	20	0.5
30	79	1040	20	1.0	40	4.1	20	0.5
Oct. 1, 1970	100	1310	20	1.0	40	4.1	20	0.5
2	100	1310	20	1.0	40	4.1	20	1.0
6	100	1310	15	1.0	49	5.0	20	1.0
7	100	1310	15	1.0	37	3.8	20	1.0

Notes

1. Purifloc A-23 was the polymer employed.
2. Carbon contact time was held constant at 30 minutes.

TABLE 16

Iron Sludge Dewatering Data

Date	Feed Rate (gpm)	Pool Depth (in.)	Influent Sludge Solids (%)	Dewatered Sludge Solids (%)	Centrate Solids (mg/l)	Volatile Solids (%)	Percent Recovery *
9-29-70	1.9	0.49	3.46	19.67	17,200	61	55
9-30-70	1.2	0.47	2.31	18.38	16,100	62	33
9-30-70	2.4	0.50	2.54	17.84	14,100	60	48
10-01-70	5.5	0.55	1.27	24.22	--	58	
10-02-70	5.5	0.55	0.84	21.75	5,800	--	32

* Calculated for sludge summary

what was centrifuge rpm?

TABLE 14

Lime Sludge Centrifugation Data

Date	Clarifier pH	Feed Rate (gpm)	Pool Depth (in)	Influent Sludge Solids (%)	Dewatered Sludge Solids (%)	Centrate Solids (mg/1)	Capture (%)	Clarifier hydraulic loading (gpd/ft²)	Conditioning Polymer	Polymer Dose (#/ton dry solids)
10/14/70	10	5.6	0.55	5.32	26.4	24,200	60	655		
	10	5.6	0.55	0.34	24.7	1,700	50	"		
10/27/70	10	1.2	0.65	4.6	20.2	8,100	86	1020		
	10	2.0	0.67	4.4	21.2	9,400	83	"		
	10	3.0	0.69	6.9	30.6	31,600	62	"		
11/4/70	11.8	1.2	0.65	9.1	29.7	12,000	90	1020		
	11.8	2.0	0.67	9.1	33.2	29,500	73	"		
	11.8	3.0	0.69	9.1	31.2	29,700	74	"		
	11.8	4.0	0.70	9.1	25.0	33,100	68	"		
	11.8	1.2	0.30	7.0	33.8	25,700	68	"		
	11.8	2.0	0.32	7.0	27.8	33,700	59	"		
	11.8	3.0	0.34	7.0	41.5	35,700	53	"		
	11.8	4.0	0.36	7.0	45.3	39,000	47	"		
11/11/70	11	1.2	0.65	11.1	32.1	45,000	69	1020		
	11	2.0	0.67	11.1	35.2	46,900	67	"		
11/13/70	10.5	1.2	0.65	10.3	28.0	40,000	73	1020		
	10.5	1.2	0.65	8.8	22.6	2,800	98	"	Hercofloc 814.2	46
	10.5	1.2	0.65	10.6	28.3	1,800	99	"	Hercofloc 814.2	6
	10.5	1.2	0.65	10.6	—	4,600			Hercofloc 814.2	4.4
11/20/70	10.5	1.2	0.65	10.9	33.1	17,400	89	1150		
	10.5	2	0.67	11.4	32.2	55,500	62	"		
	10.5	1.2	0.65	11.8	30.9	5,500	92	"	Nopcofloc 940	1.9
	10.5	2	0.67	11.9	36.2	6,700	96	"	Nopcofloc 940	1.7
	10.5	1.2	0.65	12.0	28.8	5,700	97	"	Nopcofloc 940	1.2
	10.5	2	0.67	12.0	27.9	7,500	96	"	Nopcofloc 940	1.2

TABLE 14
(Continued)

Lime Sludge Centrifugation Data

Date	Clarifier pH	Feed Rate (gpm)	Pool Depth (in.)	Influent Sludge Solids (%)	Dewatered Sludge Solids (%)	Centrate Solids (mg/1)	Capture (%)	Clarifier hydraulic loading (gpd/ft²)	Conditioning Polymer	Polymer Dose (#/ton dry sol.)
12/3/70	11.8	1.2	0.65	9.7	39.1	37,200	68	1020		0
	11.8	2.0	0.67	9.0	43.5	43,600	57	"		0
	11.8	4.0	0.70	9.0	47.0	44,500	56	"		0
12/4/70	11.8	1.2	0.65	9.13	36.0	37,300	66	983		0
	11.8	1.2	0.65	9.44	24.7	3,100	98	"	Nopcofloc 940	15.5
	11.8	1.2	0.65	10.2	25.8	2,100	99	"	Nopcofloc 940	11.8
	11.8	1.2	0.65	10.4	--	1,700	--	"	Nopcofloc 940	5.5
	11.8	1.2	0.65	10.6	25.2	22,200	87	"	Nopcofloc 940	1.6
	11.8	1.2	0.65	9.4	--	24,500	--	"	Nopcofloc 940	0.63
	11.8	1.2	0.65	7.6	--	13,900	--	"	WCL - 4097	8.5
	11.8	1.2	0.65	7.5	--	13,000	--	"	WCL - 4097	13.0
	11.8	1.2	0.65	7.5	23.9	11,700	88	"	WCL - 4097	22.2
12/15/70	10.5	2.7	0.68	7.18	22.0	2,800	57	1150	Nopcofloc 930	3.7
Reactor-	10.5	2.7	0.68	5.81	22.0	3,100	95	"	WT 2600	5.0
Clarifier	10.5	2.7	0.68	5.22	23.6	13,500	79	"	WT 2600	23.0
	10.5	2.7	0.68	5.47	27.5	19,800	69	"	Nopcofloc 800	20.0
	10.5	2.7	0.68	5.47	33.7	17,800	70	"	Nopcofloc 720	23.0
2/10/71	10.5	1.2	0.65	13.4	36.8	40,400	79	900		0
	10.5	2.0	0.67	13.4	38.1	62,300	64	"		0
	10.5	3.0	0.70	13.4	36.3	52,300	71	"		0
5000 rpm ↑	10.5	4.0	0.72	13.4	34.8	73,900	57	"		0
	10.5	5.0	0.73	13.4	36.4	55,900	69	"		0
	10.5	2.0	0.67	13.4	25.8	18,800	92	"	Nopcofloc 940	0.81
	10.5	3.0	0.70	13.4	27.7	5,500	98	"	Nopcofloc 940	0.84
	10.5	4.0	0.72	13.4	29.4	5,400	98	"	Nopcofloc 940	1.36
3500 rpm ↓	10.5*	1.2	0.65	13.4	34.5	102,900	34	"		0
	10.5*	2.0	0.67	13.4	35.1	74,400	57	"		0
	10.5*	3.0	0.70	13.4	35.8	72,400	58	"		0

*Indicates centrifuge at 3500 rpm all other data at 5000 rpm.

TABLE 14
(Continued)

Lime Sludge Centrifugation Data

Date	Clarifier pH	Feed Rate (gpm)	Pool Depth (in.)	Influent Sludge Solids (%)	Dewatered Sludge Solids (%)	Centrate Solids (mg/l)	Capture (%)	Clarifier hydraulic loading (gpd/ft²)	Conditioning Polymer	Polymer Dose (#/ton dry sol.)
2/10/71	10.5*	4.0	0.72	13.4	36.1	69,400	60	900		0
	10.5*	2.0	0.67	13.4	26.5	55,300	74	"	Nopcofloc 940	0.14
	10.5*	3.0	0.70	13.4	26.3	13,100	95	"	Nopcofloc 940	1.14
	10.5*	4.0	0.72	13.4	29.0	9,100	96	"	Nopcofloc 940	1.71
	10.5*	5.0	0.73	13.4	30.2	25,200	89	"	Nopcofloc 940	1.73
	10.5*	2.0	0.51	13.4	27.4	5,800	98	"	Nopcofloc 940	1.35
	10.5*	3.0	0.53	13.4	27.7	10,600	96	"	Nopcofloc 940	1.44
	10.5*	4.0	0.54	13.4	29.3	12,000	95	"	Nopcofloc 940	1.96
2/19/71	10.5*	2.0	0.51	8.4	19.2	2,800	98	1040	Nopcofloc 930	1.4
	10.5*	3.0	0.53	8.4	19.9	6,100	96	"	Nopcofloc 930	1.4
	10.5*	4.0	0.54	8.4	20.9	9,000	93	"	Nopcofloc 930	1.4
	10.5*	5.0	0.55	8.4	21.4	17,000	87	"	Nopcofloc 930	1.4
	10.5*	6.0	0.57	8.4	25.3	36,000	67	"	Nopcofloc 930	1.4
	10.5*	7.0	0.58	8.4	27.2	39,000	63	"	Nopcofloc 930	1.4
	10.5*	2.0	0.67	8.4	20.1	4,400	97	"	Nopcofloc 930	1.4
	10.5*	3.0	0.70	8.4	21.1	4,700	96	"	Nopcofloc 930	1.4
	10.5*	4.0	0.72	8.4	20.7	6,600	95	"	Nopcofloc 930	1.4
3500	10.5*	5.0	0.73	8.4	21.7	17,000	87	"	Nopcofloc 930	1.4
↑ rpm	10.5*	6.0	0.75	8.4	26.4	33,000	69	"	Nopcofloc 930	1.4
	10.5*	7.0	0.76	8.4	26.4	37,000	65	"	Nopcofloc 930	1.4
	10.5	2.0	0.67	8.4	29.3	---	--	"	Nopcofloc 930	1.4
↓ 5000	10.5	4.0	0.72	8.4	32.1	26,000	75	"	Nopcofloc 930	1.4
rpm	10.5	6.0	0.75	8.4	26.5	17,000	85	"	Nopcofloc 930	1.4
	10.5	7.0	0.76	8.4	26.9	22,000	80	"	Nopcofloc 930	1.4

*Indicates centrifuge at 3500 rpm all other data at 5000 rpm

probably 940

TABLE 14
(Continued)

Lime Sludge Centrifugation Data

Date	Clarifier pH	Feed Rate (gpm)	Pool Depth (in.)	Influent Sludge Solids (%)	Dewatered Sludge Solids (%)	Centrate Solids (mg/1)	Capture (%)	Clarifier hydraulic loading (gpd/ft²)	Conditioning Polymer	Polymer Dose (#/ton dry sol.)
2/19/71	10.5	2.0	0.50	8.4	19.2	2,800	98	1040	Nopcofloc 940	1.4
These figures	10.5	3.0	0.53	8.4	19.9	6,100	96	"	Nopcofloc 940	1.4
are nearly	10.5	4.0	0.54	8.4	20.9	9,000	93	"	Nopcofloc 940	1.4
identical to	10.5	5.0	0.56	8.4	21.4	17,000	87	"	Nopcofloc 940	1.4
the 2/19/71	10.5	6.0	0.57	8.4	25.3	36,000	67	"	Nopcofloc 940	1.4
data on the	10.5	7.0	0.58	8.4	27.2	39,000	63	"	Nopcofloc 940	1.4
preceding page	10.5	2.0	0.68	8.4	20.1	4,400	97	"	Nopcofloc 940	1.4
	10.5	3.0	0.70	8.4	21.1	4,700	96	"	Nopcofloc 940	1.4
	10.5	4.0	0.72	8.4	20.7	6,600	95	"	Nopcofloc 940	1.4
	10.5	5.0	0.73	8.4	21.7	17,000	87	"	Nopcofloc 940	1.4
	10.5	6.0	0.75	8.4	26.4	33,000	69	"	Nopcofloc 940	1.4
	10.5	7.0	0.76	8.4	26.4	37,000	65	"	Nopcofloc 940	1.4
	10.5	2.0	0.66	8.4	29.3	---	--	"	Nopcofloc 940	1.4
	10.5	4.0	0.70	8.4	32.1	26,000	75	"	Nopcofloc 940	1.4
	10.5	6.0	0.72	8.4	26.5	17,000	85	"	Nopcofloc 940	1.4
	10.5	7.0	0.74	8.4	26.9	22,000	80	"	Nopcofloc 940	1.4
3/2/71	10.5	2.0	0.67	7.4	23.4	2,600	97	960	Nopcofloc 940	1.31
	10.5	4.0	0.72	7.4	21.0	4,200	96	"	Nopcofloc 940	1.69
	10.5	6.0	0.73	7.4	--	---	<90	"	Nopcofloc 940	4.30
Fig. 71	10.5	2.0	0.68	7.4	21.0	3,300	98	"	Nopcofloc 940	1.23
indicates	10.5	3.0	0.70	7.4	13.1	4,700	97	"	Nopcofloc 940	1.59
3500 rpm	10.5	4.0	0.72	7.4	28.3	4,000	95	"	Nopcofloc 940	2.02
	10.5	5.0	0.73	7.4	24.0	34,000	--	"	Nopcofloc 940	6.83
	10.5	2.0	0.50	7.4	2.19	6,500	94	"	Nopcofloc 940	1.31
	10.5	2.0	0.50	7.4	20.6	12,000	89	"	Nopcofloc 940	1.23
	10.5	2.0	0.50	7.4	21.7	5,200	95	"	Nopcofloc 940	1.59
	10.5	3.0	0.53	7.4	23.2	2,000	98	"	Nopcofloc 940	1.59
	10.5	4.0	0.54	7.4	23.6	4,400	96	"	Nopcofloc 940	2.94
	10.5	3.0	0.53	7.4	22.0	32,000	74	"	Nopcofloc 940	1.46
	10.5	3.0	0.53	7.4	22.3	2,600	97	"	Nopcofloc 940	1.96

TABLE 14
(Continued)

Lime Sludge Centrifugation Data

Date	Clarifier pH	Feed Rate (gpm)	Pool Depth (in.)	Influent Sludge Solids (%)	Dewatered Sludge Solids (%)	Centrate Solids (mg/1)	Capture (%)	Clarifier hydraulic loading (gpd/ft²)	Conditioning Polymer	Polymer Dose (#/ton dry sol.)
3/3/71	10.5	2.0	0.50	6.4	25.0	9,000	89	960	Nopcofloc 940	1.15
	10.5	2.0	0.50	6.4	25.7	1,600	98	"	Nopcofloc 940	1.70
	10.5	3.0	0.53	6.4	24.4	6,100	93	"	Nopcofloc 940	1.87
	10.5	3.0	0.53	6.4	24.7	4,300	95	"	Nopcofloc 940	1.53
	10.5	4.0	0.54	6.4	27.1	4,200	95	"	Nopcofloc 940	3.40
	10.5	2.0	0.69	6.4	21.7	3,200	97	"	Nopcofloc 940	1.28
	10.5	2.0	0.67	6.4	21.0	9,500	89	"	Nopcofloc 940	1.42
	10.5	2.0	0.67	6.4	24.9	2,100	98	"	Nopcofloc 940	1.70
	10.5	3.0	0.70	6.4	23.1	---	--	"	Nopcofloc 940	1.32
	10.5	3.0	0.70	6.4	20.6	2,400	98	"	Nopcofloc 940	1.56
	10.5	3.0	0.70	6.4	23.6	---	--	"	Nopcofloc 940	1.90
	10.5	4.0	0.72	6.4	28.6	5,000	94	"	Nopcofloc 940	1.42
	10.5	4.0	0.72	6.4	23.7	4,200	95	"	Nopcofloc 940	1.63
	10.5	4.0	0.72	6.4	25.0	3,500	95	"	Nopcofloc 940	1.90
	10.5	5.0	0.73	6.4	--	---	<90	"	Nopcofloc 940	5.96
3/5/71	10.5	2.0	0.68	5.1	--	3,000	~95	1020	Atlasep 2A2	0.8
	10.5	2.0	0.68	5.1	--	---	~95	"	Atlasep 3A3	3.5
	10.5	2.0	0.68	5.1	--	---	<95	"	Hercofloc 810	5.8
	10.5	2.0	0.68	5.1	--	---	<95	"	Magnifloc 560C	5.8
	10.5	2.0	0.68	5.1	--	---	~95	"	Magnifloc 837A	4.6
	10.5	2.0	0.68	5.1	--	---	<95	"	Magnifloc 835A	5.8
	10.5	2.0	0.68	5.1	--	---	~95	"	Magnifloc EP721	5.8
	10.5	2.0	0.68	5.1	--	---	~95	"	Magnifloc 836A	4.1
	10.5	2.0	0.68	5.1	--	---	<95	"	Magnifloc 521C	5.8
	10.5	2.0	0.68	5.1	--	---	<95	"	Magnifloc 570C	5.8
	10.5	2.0	0.68	5.1	--	---	<95	"	Magnifloc 571C	5.8
	10.5	2.0	0.68	5.1	20.4	3,400	95	"	Polyfloc 1120	1.2
	10.5	2.0	0.68	5.1	--	---	~95	"	Purifloc A23	3.5
	10.5	2.0	0.68	5.1	--	---	~95	"	Nopcofloc 940	1.4
	10.5	2.0	0.68	5.1	--	---	>95	"	Calgon WT 2630	5.8
	10.5	2.0	0.68	5.1	21.2	3,300	95	"	Calgon WT 2900	1.2
	10.5	2.0	0.68	5.1	20.1	4,000	94	"	Calgon WT 3000	1.4

Fig. 72 indicates 3500 rpm

TABLE 14
(Continued)

Lime Sludge Centrifugation Data

Date	Clarifier pH	Feed Rate (gpm)	Pool Depth (in.)	Influent Sludge Solids (%)	Dewatered Sludge Solids (%)	Centrate Solids (mg/l)	Capture (%)	Clarifier hydraulic loading (gpd/ft²)	Conditioning Polymer	Polymer Dose (#/ton dry sol.)
3/18/71	10.5	2.0	0.68	10.7	--	8,000	-96	1040	Nopcofloc 940	1.26
	10.5	2.0	0.68	10.7	23.5	6,800	96	"	Nopcofloc 940	1.48
	10.5	2.0	0.68	10.7	--	2,900	-99	"	Nopcofloc 940	1.59
	10.5	3.0	0.70	10.7	32.1	7,100	96	"	Nopcofloc 940	1.26
	10.5	3.0	0.70	10.7	--	7,600	-95	"	Nopcofloc 940	1.37
Fig 68	10.5	4.0	0.72	10.7	26.4	4,200	98	"	Nopcofloc 940	1.76
indicates	10.5	2.0	0.68	10.7	--	19,800	-88	"	Nopcofloc 940	1.58
3500 rpm	10.5	2.0	0.68	10.7	29.5	47,600	67	"	Nopcofloc 940	0.63
	10.5	2.0	0.68	10.7	--	59,700	-57	"	Nopcofloc 940	.80
	10.5	2.0	0.68	10.7	23.7	27,700	84	"	Nopcofloc 940	.91
	10.5	2.0	0.68	10.7	--	22,600	-87	"	Nopcofloc 940	.91
	10.5	2.0	0.68	10.7	22.7	14,600	92	"	Nopcofloc 940	1.02
	10.5	2.0	0.68	10.7	--	19,400	-90	"	Nopcofloc 940	1.21
	10.5	2.0	0.68	10.7	22.8	10,100	95	"	Nopcofloc 940	1.29
	10.5	2.0	0.68	10.7	--	7,000	-96	"	Nopcofloc 940	1.37
	10.5	2.0	0.68	10.7	25.3	7,000	96	"	Nopcofloc 940	1.48
	10.5	2.0	0.68	10.7	--	3,600	-98	"	Nopcofloc 940	1.59
	10.5	2.0	0.68	10.7	25.9	3,200	99	"	Nopcofloc 940	1.70
	10.5	2.0	0.68	10.7	--	3,100	-99	"	Nopcofloc 940	1.81
3/24/71	10.5	2.0	0.68	7.78	--	10,300	-90	1280	Nopcofloc 940	0.47
	10.5	2.0	0.68	7.78	24.4	17,200	84	"	Nopcofloc 940	0.32
	10.5	2.0	0.68	7.78	--	12,800	-88	"	Nopcofloc 940	0.63
	10.5	2.0	0.68	7.78	22.6	12,500	89	"	Nopcofloc 940	0.71
Fig. 69	10.5	2.0	0.68	7.78	--	3,700	-97	"	Nopcofloc 940	0.87
indicates	10.5	2.0	0.68	7.78	22.0	2,700	98	"	Nopcofloc 940	1.10
	10.5	2.0	0.68	7.78	--	2,700	-98	"	Nopcofloc 940	1.26
3500 rpm	10.5	2.0	0.68	7.78	22.2	2,500	99	"	Nopcofloc 940	1.42
	10.5	2.0	0.68	7.78	--	2,500	-98	"	Nopcofloc 940	1.57
	10.5	2.0	0.68	7.78	22.7	900	99	"	Nopcofloc 940	1.62
	10.5	2.0	0.68	7.78	--	22,000	-80	"	Atlasep 2A2	0.32
	10.5	2.0	0.68	7.78	20.6	8,500	93	"	Atlasep 2A2	0.55
	10.5	2.0	0.68	7.78	--	3,000	-98	"	Atlasep 2A2	0.71
	10.5	2.0	0.68	7.78	20.9	3,700	97	"	Atlasep 2A2	0.94
	10.5	2.0	0.68	7.78	--	3,300	-97	"	Atlasep 2A2	1.11
	10.5	2.0	0.68	7.78	21.0	3,100	98	"	Atlasep 2A2	1.69

TABLE 15

Lime Sludge Vacuum Filtration Data

Date	Clarifier Loading Rate $(gal\ da^{-1}\ ft^{-2})$	Clarifier pH	Feed Rate (gpm)	Pool Depth (in.)	Filtration Rate (#/ ft^2/hr)	Influent Sludge Solids (%)	Dewatered Sludge Solids (%)	Filtrate Solids (mg/l)	Capture (%)	Polymer Dose (#/ton dry sol.)
10-16-70	655	10.0	1.8	13	--	6.6	19.8	6,500	94	0
10-21-70	700	10.0	1.3	13	--	7.4	16.4	18,100	85	0
REACTOR CLARIFIER	"	10.0	1.3	13	--	0.5	15.4	4,600	8	0
10-28-70	1020	10.0	1.2	15	--	6.5	20.5	11,600	87	0
11-03-70	1020	11.8	1.7	12	--	11.5	31.1	8,200	96	0
	"	11.8	1.7	12	--	6.8	26.4	16,000	81	0
	"	11.8	1.7	12	--	6.6	26.3	--	63	0
11-05-70	1020	12.2	1.7	15	1.9	4.3	21.6	18,500	58	0
	"	12.2	1.7	15	3.3	6.0	18.5	31,000	--	0
11-16-70	1020	10.5	--	15	--	11.4	24.1	25,000	87	0
11-18-70	1020	10.5	1.2	15	5.9	9.9	21.3	9,800	94	4.2*
	"	10.5	1.2	15	4.1	10.0	21.8	4,490	97	0
	"	10.5	1.2	15	4.4	9.3	18.6	12,200	93	2.5*
	"	10.5	1.2	15	3.7	11.0	21.2	8,900	96	0
	"	10.5	1.2	15	4.8	12.1	23.9	9,000	96	5.2*
	"	10.5	1.2	15	5.0	10.7	22.2	3,900	98	9.3*

*Hercofloc 814.2

TABLE 15
(Continued)

Lime Sludge Vacuum Filtration Data

Date	Clarifier Loading Rate (gal da⁻¹ ft⁻²)	Clarifier pH	Feed Rate (gpm)	Percent Immersion	Pool Depth (in.)	Filter Speed (rph)	Cycle Time (min)	Filtration Rate (#/ft^2/hr)	Influent Sludge Solids (%)	Dewatered Sludge Solids (%)	Filtrate Solids (mg/l)	Capture (%)	Polymer Dose (#/ton dry sol.)
12/3/70	1020	11.8	1.2	45	15			---	9.0	24.4	---	—	0
2/17/71	960	10.5	1.5	"	15	10	6	2.8	14.1	33.1	43,200	80	0
	"	10.5	1.5	"	15	20	3	4.6	14.1	31.7	30,600	86	0
	"	10.5	1.5	"	15	30	2	4.7	14.1	31.0	44,900	80	0
	"	10.5	1.5	"	15	40	1.5	7.0	14.1	29.4	39,900	83	0
	"	10.5	1.5	"	15	10	6	2.8	14.1	30.1	43,500	81	1.7
	"	10.5	1.5	"	15	20	3	6.9	14.1	30.7	31,300	87	1.7
	"	10.5	1.5	"	15	30	2	13.9	14.1	37.8	13,400	94	1.7
	"	10.5	1.5	"	15			3.6	14.1	--	5,200	--	3.6
2/26/71	1040	10.5	1.2	39	12	10	6	3.6	13.4	36.1	12,000	94	0.7
	"	10.5	1.2	"	12	20	3	5.6	13.4	35.1	14,000	93	0.7
	"	10.5	1.2	"	12	30	2	8.5	13.4	30.9	14,000	94	0.7
	"	10.5	1.2	"	12	40	1.5	10.4	13.4	25.6	17,000	93	0.7
	"	10.5	2.0	35	10	50	1.2	12.9	13.4	30.9	21,000	90	0.7
	"	10.5	2.5	39	12	60	1	12.1	13.4	25.6	17,000	94	0.8
	"	10.5	2.2	43	14	10	6	8.5	13.4	31.6	5,300	98	1.4

NOTE: Nopcofloc used as conditioning polymer as of 2/17/71.

TABLE 15
(Continued)

Lime Sludge Vacuum Filtration Data

Date	Clarifier pH	Clarifier loading rate (gal da.$^{-1}$ ft^{-2})	Feed Rate (gpm)	Percent Immersion	Pool Depth (in.)	Filtration Rate (#/ft^2/hr)	Filter Speed (rph)	Cycle Time (min.)	Influent Sludge Solids (%)	Dewatered Sludge Solids (%)	Filtrate Solids (mg/l)	Capture (%)	Polymer Dose (#/ton dry sol.)
2/26/71	10.5	1040	2.2	43	14	12.8	20	3	13.4	29.3	4,200	98	1.4
	10.5	"	2.2	39	12	15.0	30	2	13.4	30.2	8,100	97	1.4
	10.5	"	2.2	39	12	19.1	40	1.5	13.4	27.1	13,000	95	1.4
3/9/71	10.5	1040	1.5	"		3.5	10	6	9.9	25.7	4,800	97	1.0
	10.5	"	1.5	"		7.5	20	3	9.9	23.4	3,600	97	1.0
	10.5	"	2.5	"		11.0	30	2	9.9	23.5	8,400	95	1.2
	10.5	"	2.5	"		8.8	40	1.5	9.9	21.2	7,400	96	1.2
	10.5	"	3.2	"		12.5	40	1.5	9.9	19.9	8,000	96	1.3
	10.5	"	3.2	"		13.7	50	1.2	9.9	20.5	4,900	97	1.3
	10.5	"	3.2	"		--	20		9.9	20.7	7,100	96	1.3
	10.5	"	3.2	"		—			9.9	--	5,100	97	1.3
	10.5	"	3.2	"		13.0	50	1.2	9.9	19.1	10,400	87	1.3
3/12/71	10.5	1040	2.6	"	12	2.8	10	6	6.3	29.0	6,500	92	0.9
	10.5	"	2.6	"	12	4.9	20	3	6.3	25.8	9,500	89	0.9
	10.5	"	2.6	"	12	6.9	20	2	6.3	23.3	11,800	86	0.9
	10.5	"	2.6	"	12	6.6	20	3	6.3	29.0	8,700	89	0.9
	10.5	"	3.2	"	12	4.8	10	6	6.3	25.0	3,300	96	1.9
	10.5	"	3.2	"	12	5.4	20	3	6.3	25.0	5,600	94	1.9

NOTE: Nopcofloc used as conditioning polymer as of 2/17/71.

TABLE 15
(Continued)

Lime Sludge Vacuum Filtration Data

Date	Clarifier loading rate (gal da.$^{-1}$ ft^{-2})	Clarifier pH	Feed Rate (gpm)	Percent Immersion	Pool Depth (in.)	Filtration Rate (#/ft^2/hr)	Filter Speed (rph)	Cycle Time (min)	Influent Sludge Solids (%)	Dewatered Sludge Solids (%)	Filtrate Solids (mg/1)	Capture (%)	Polymer Dose (#/ton dry sol.)
3/12/71	1040	10.5	3.2	39	12	8.4	30	2	6.3	22.9	5,600	93	1.9
	"	10.5	3.2	"	12	11.4	40	1.5	6.3	21.8	8,200	91	1.9
	"	10.5	3.2	"	12	16.7	50	1.2	6.3	23.9	18,200	77	1.9
	"	10.5	3.2	"	12	4.0	10	6	6.3	28.5	5,700	93	1.9
	"	10.5	3.2	"	12	--			6.3	25.1	6,700	92	1.9

NOTE: Nopcofloc used as conditioning polymer as of 2/17/71.

TABLE 17 S

Calcination of Sludge Samples from the Cleveland Westerly Pilot Plant: Comparison of Quantities and Composition of Sludge from Low and High pH Operation

BASIS: 400 lb volatile sludge solids

		low pH	high pH
Non-Volatile Solids before Calcination (lb)		600	1332
Non-Volatile Solids after Calcination (lb)		468.4	941
Composition of Calcined Solids			
Weight (lb) (Percent)	CaO	157.8 (33.8)	468 (49.8)
	MgO	16.6 (3.5)	46 (4.9)
	hydroxyapatite	54 (11.5)	67 (7.1)
	ash	240 (51.2)	360 (38.2)
	Total	468.4 (100)	941 (100)

FIGURE 39

FLOW SHEET OF THE WESTERLY PILOT PLANT

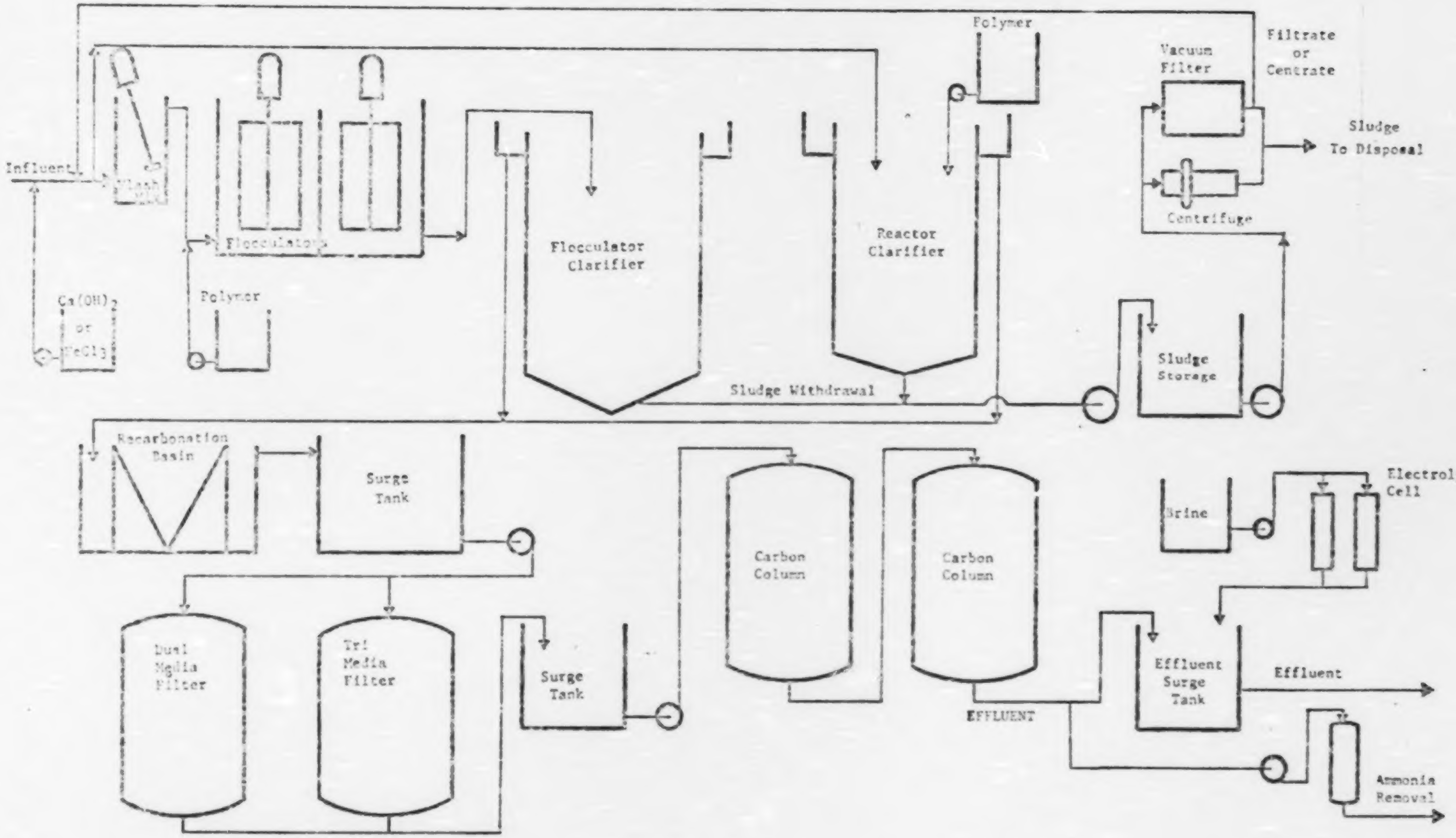

Influent
Flash Mix
Ca(OH)$_2$ or FeCl$_3$
Flocculators
Polymer
Flocculator Clarifier
Reactor Clarifier
Polymer
Sludge Withdrawal
Vacuum Filter
Centrifuge
Filtrate or Centrate
Sludge To Disposal
Sludge Storage
Recarbonation Basin
Surge Tank
Dual Media Filter
Tri Media Filter
Surge Tank
Carbon Column
Carbon Column
EFFLUENT
Brine
Electrolytic Cell
Effluent Surge Tank
Effluent
Ammonia Removal

FIGURE 36

Buchner Funnel Dewatering Tests (8/5/70)

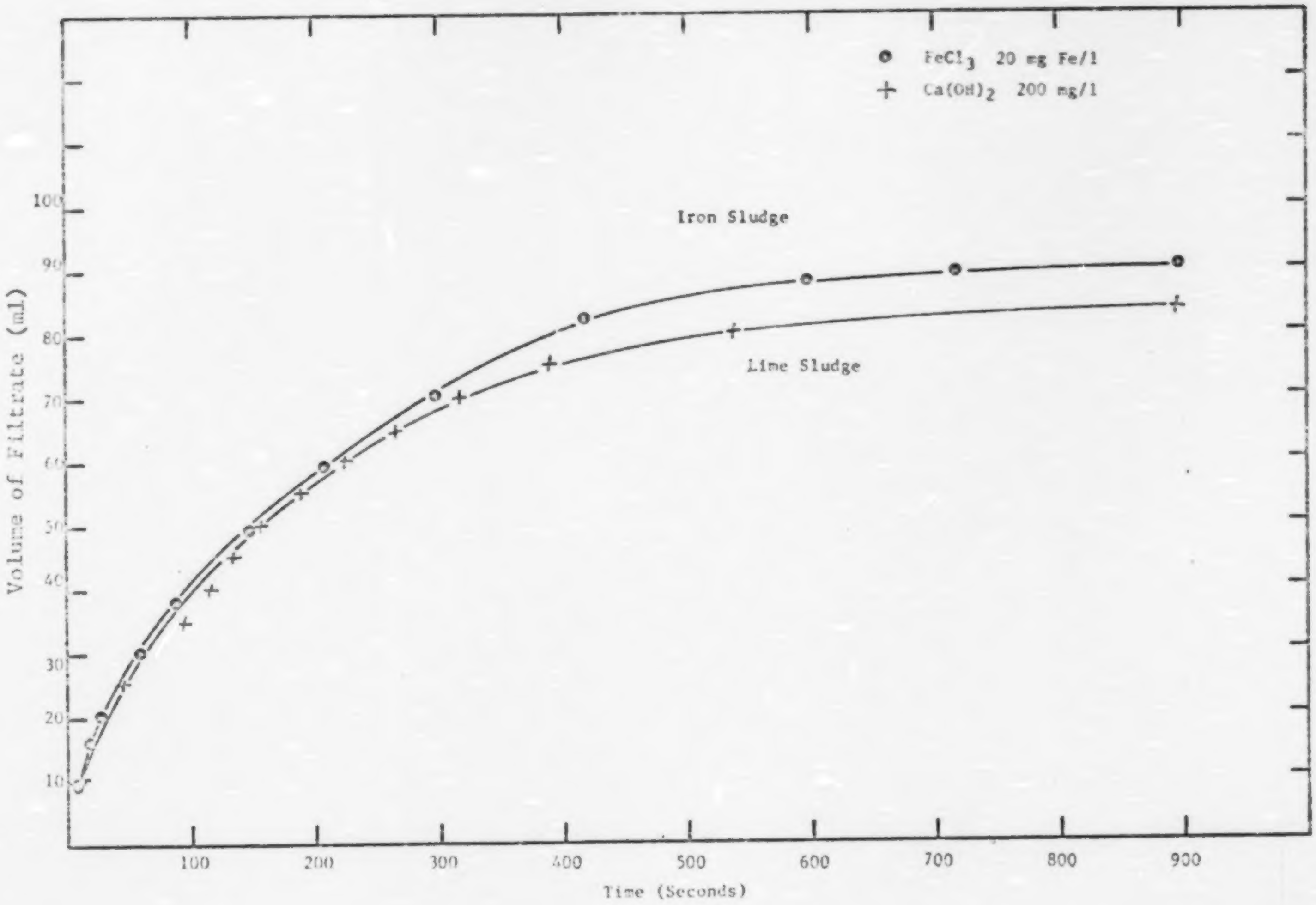


FIGURE 37

Buchner Funnel Dewatering Tests (8/19/70)

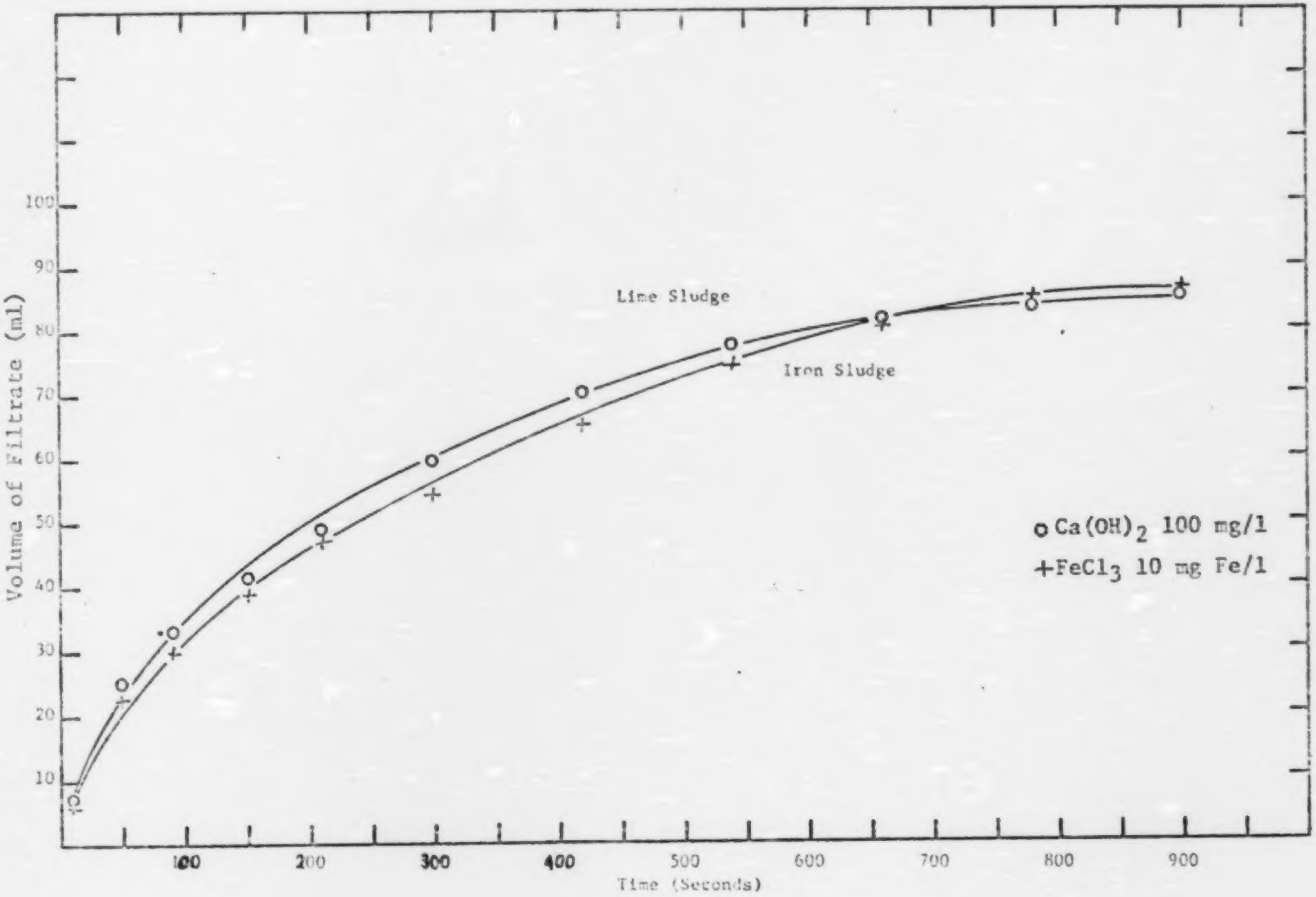


FIGURE 38

Buchner Funnel Dewatering Tests (8/21/70)

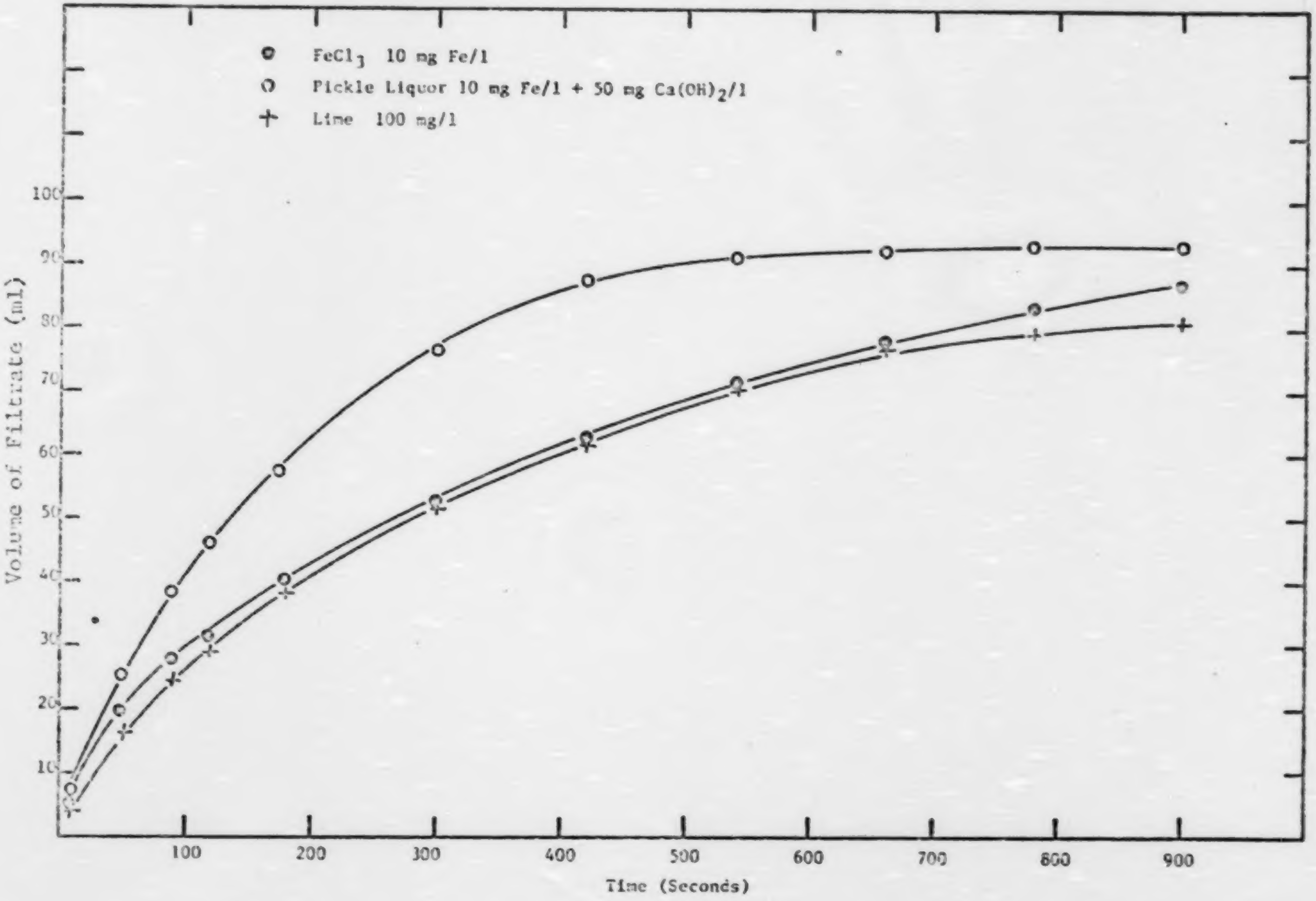


FIGURE 59
Relationship between Lime Dose and pH

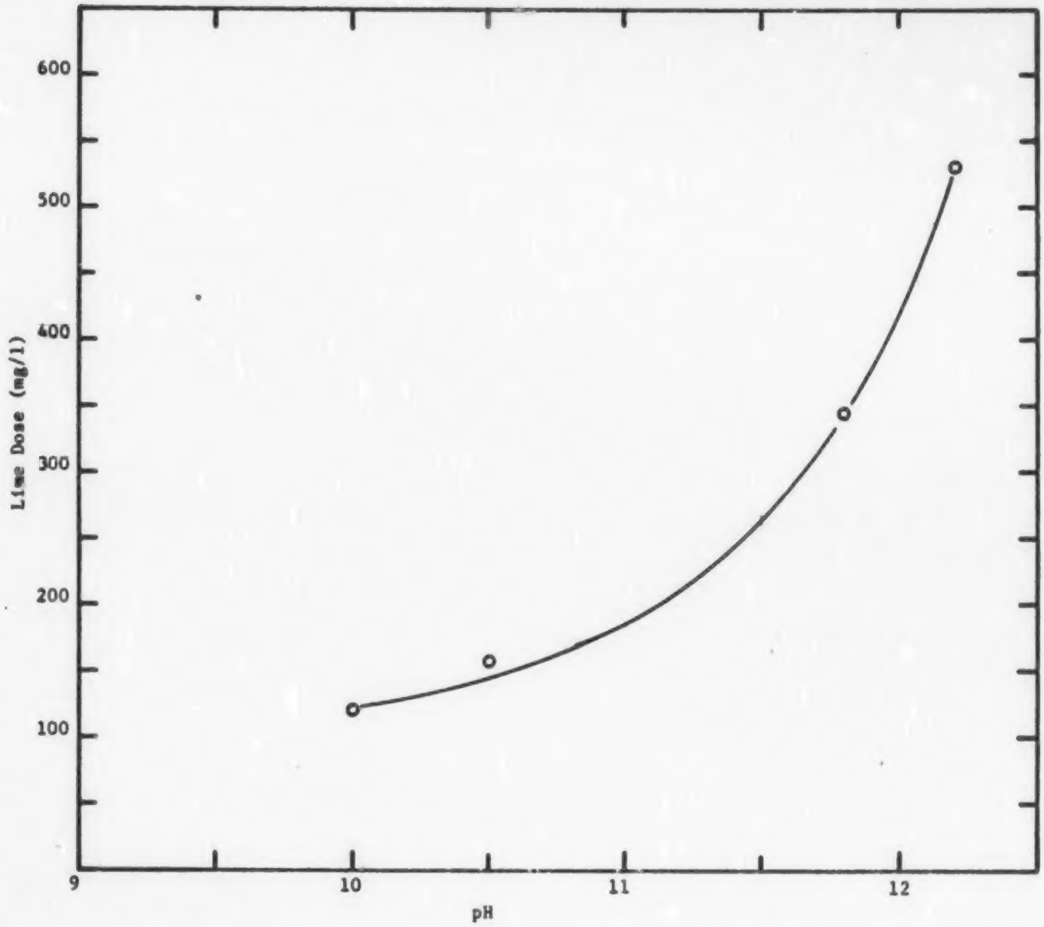


Figure 68

Effect of Polymer Dose on Centrifuge Capture - 3/18/71

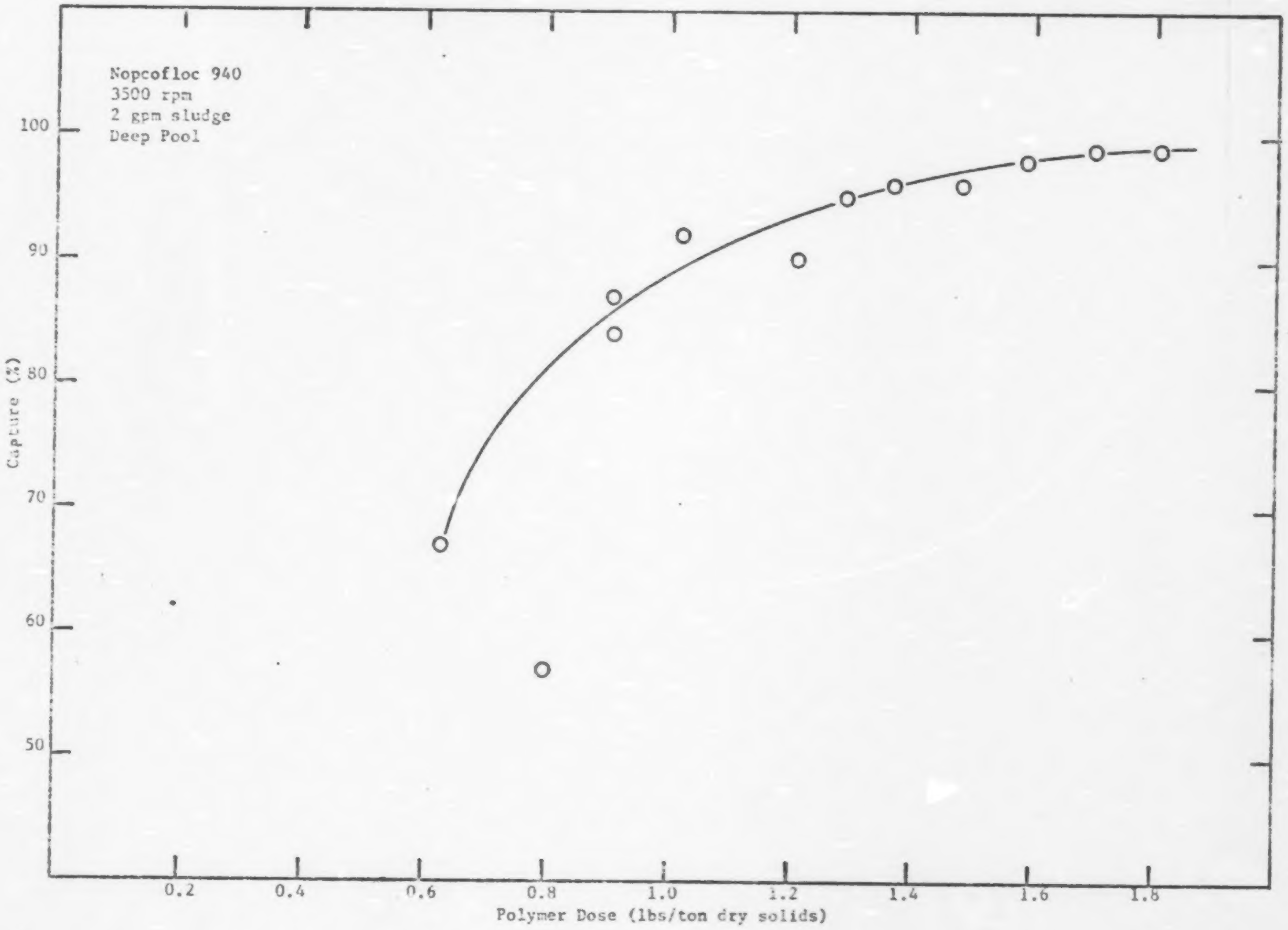


Figure 69

Effect of Polymer Dose on Centrifuge Capture - 3/24/71

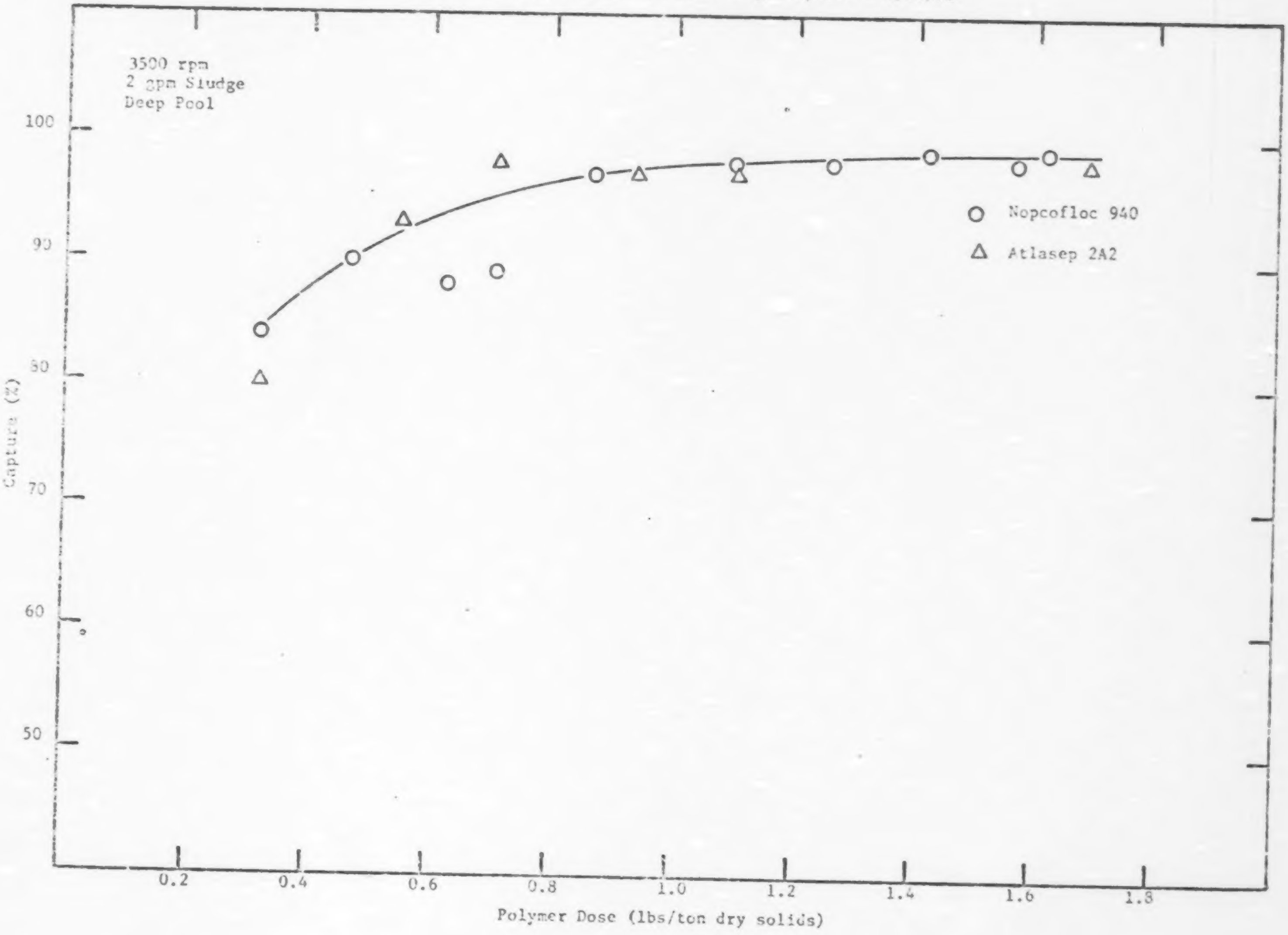
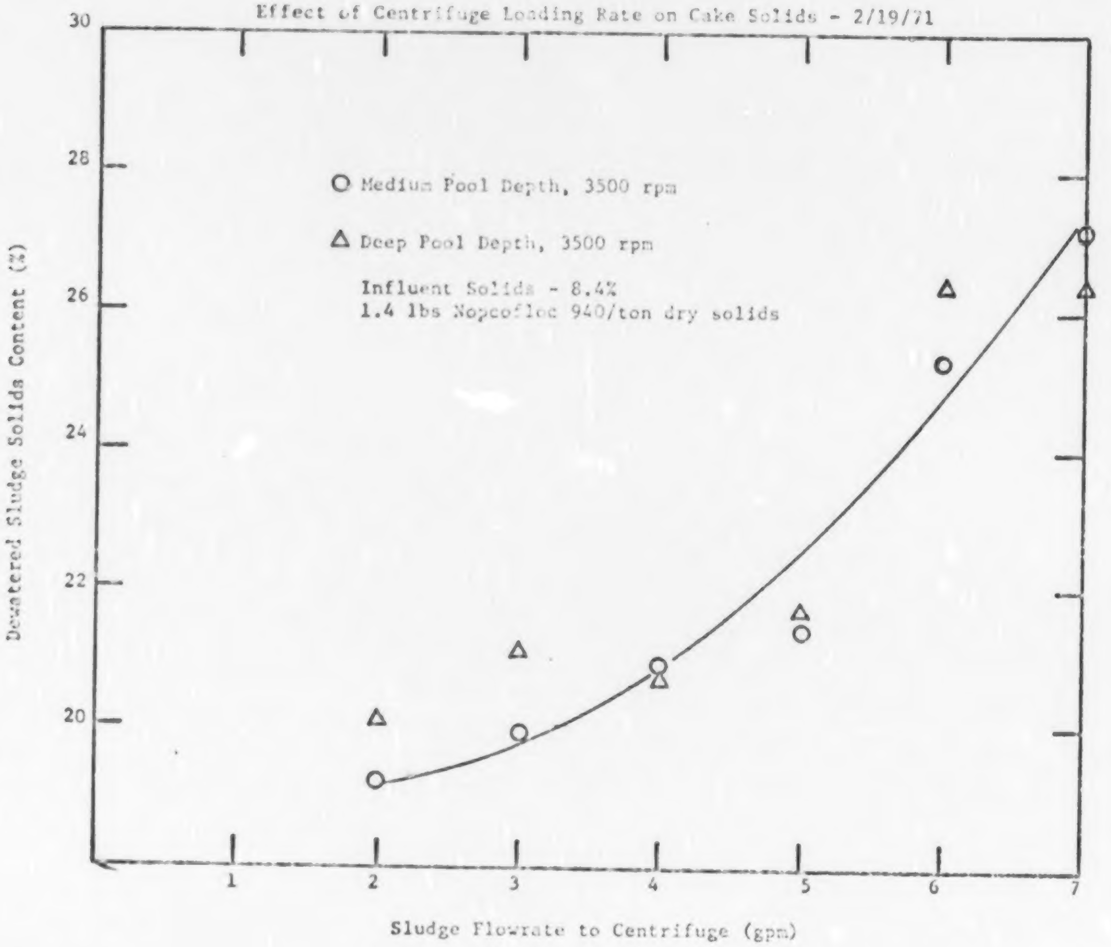


Figure 70

Effect of Centrifuge Loading Rate on Cake Solids - 2/19/71

100



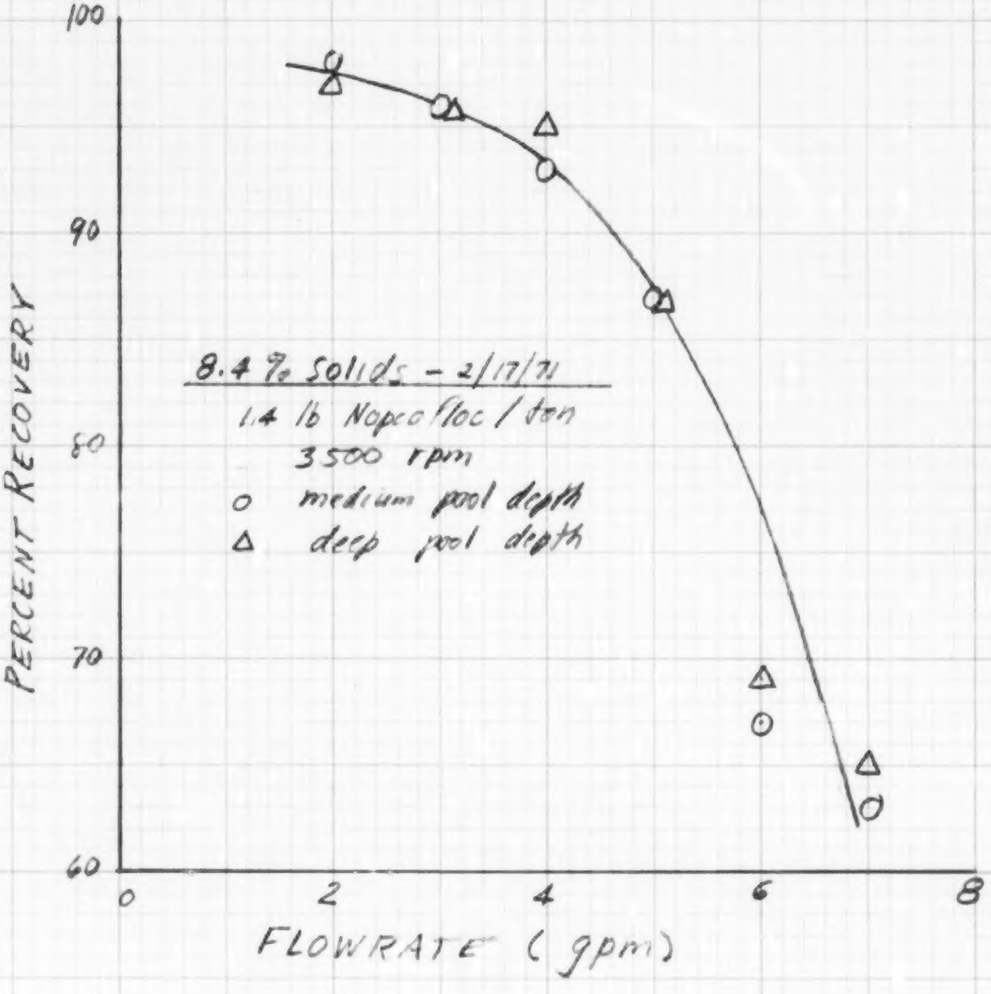


FIG 70S: EFFECT OF SLUDGE FLOWRATE ON SOLIDS RECOVERY

Figure 71

Effect of Centrifuge Loading Rate on Cake Solids - 3/2/71

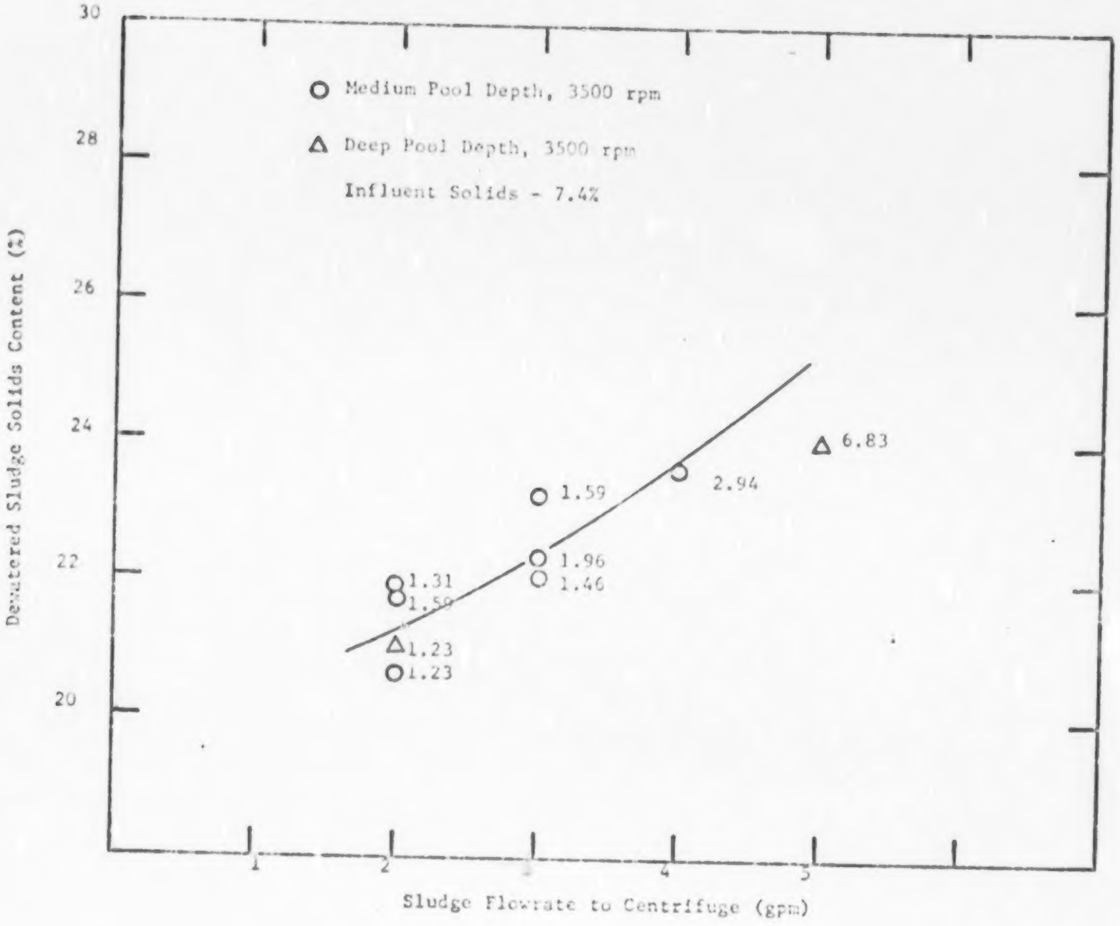
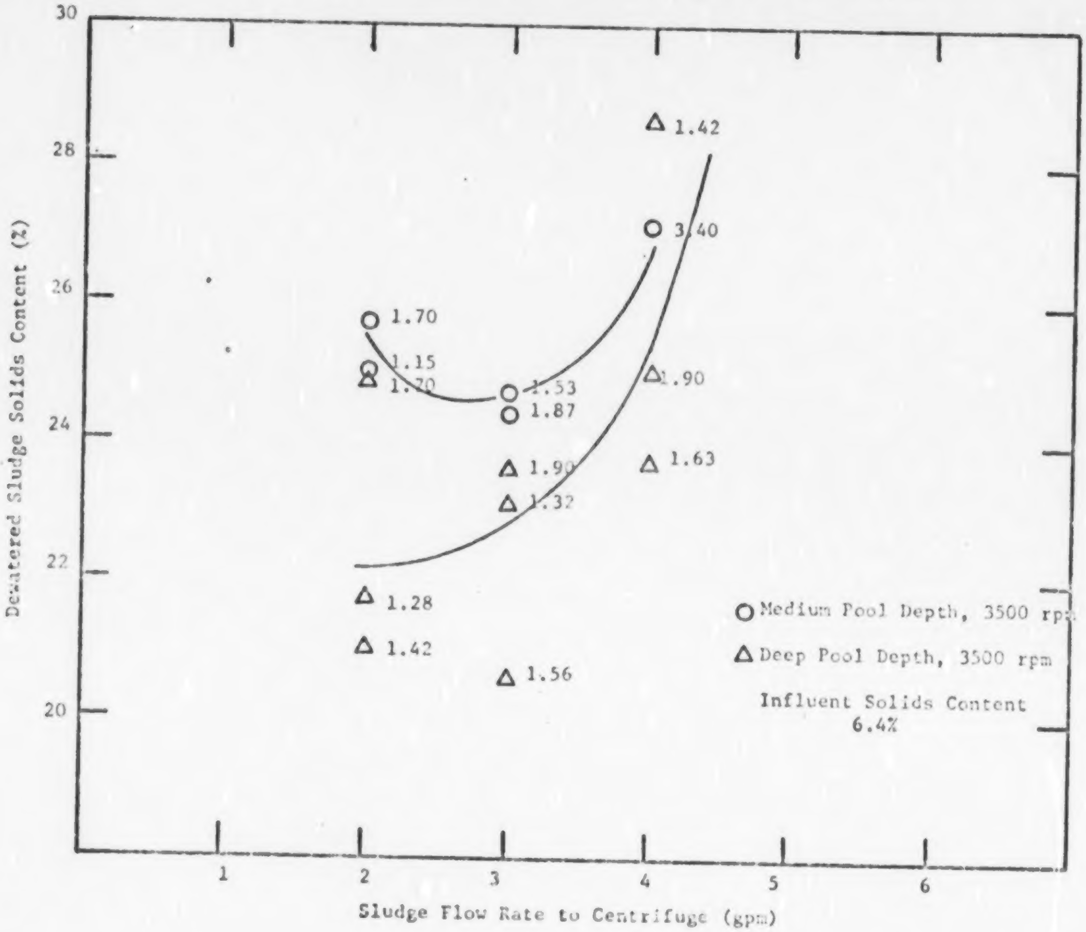


Figure 72
Effect of Centrifuge Loading Rate on Cake Solids - 3/3/71



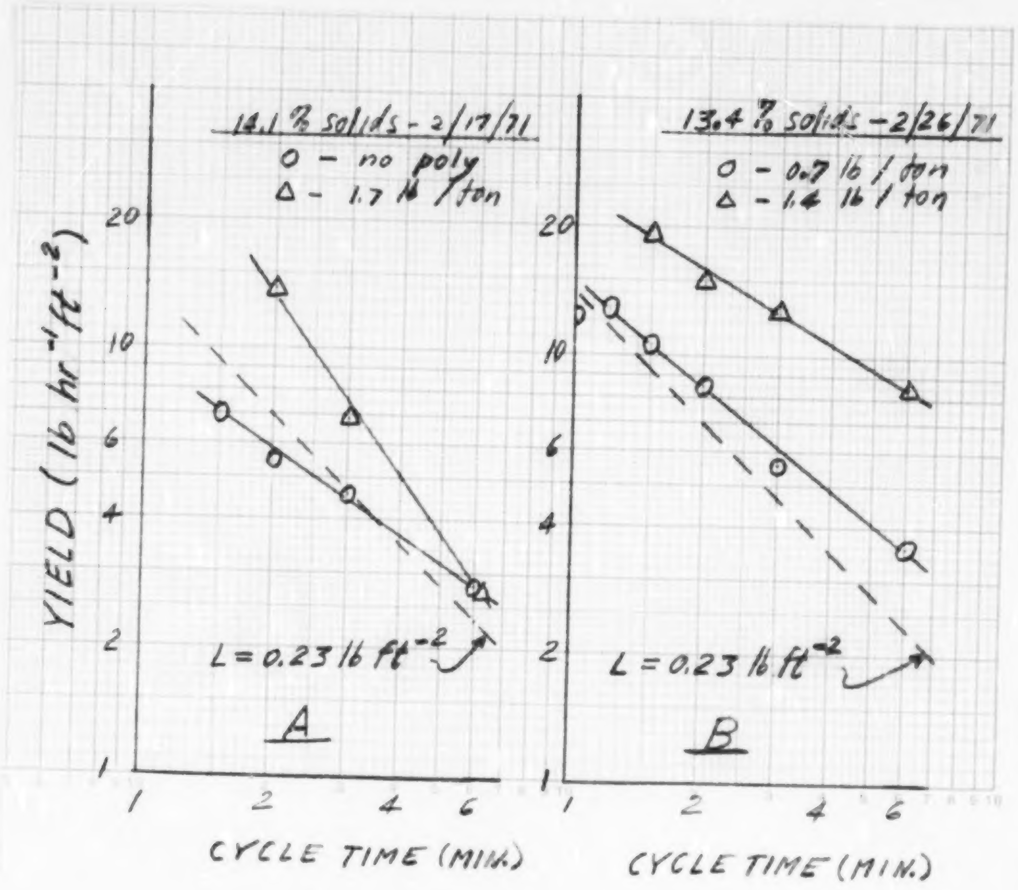


FIG 73S EFFECT OF CYCLE TIME ON FILTER YIELD

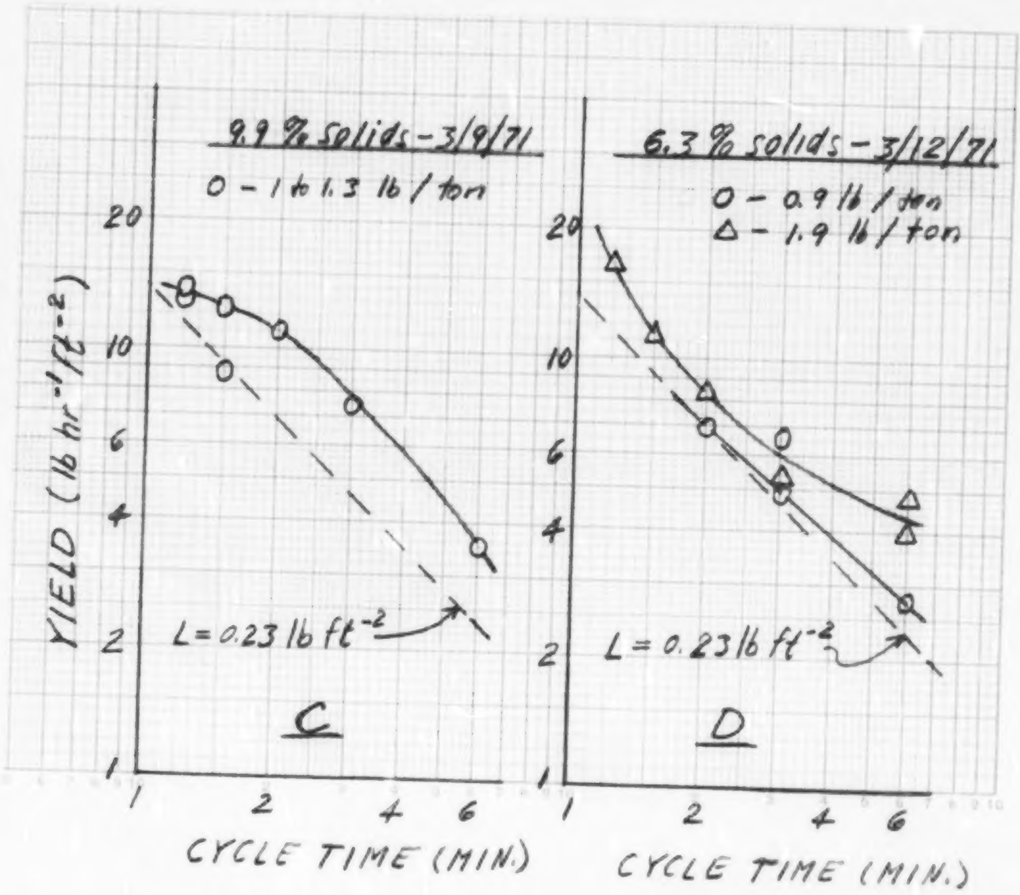


FIG.74S EFFECT OF CYCLE TIME ON FILTER YIELD

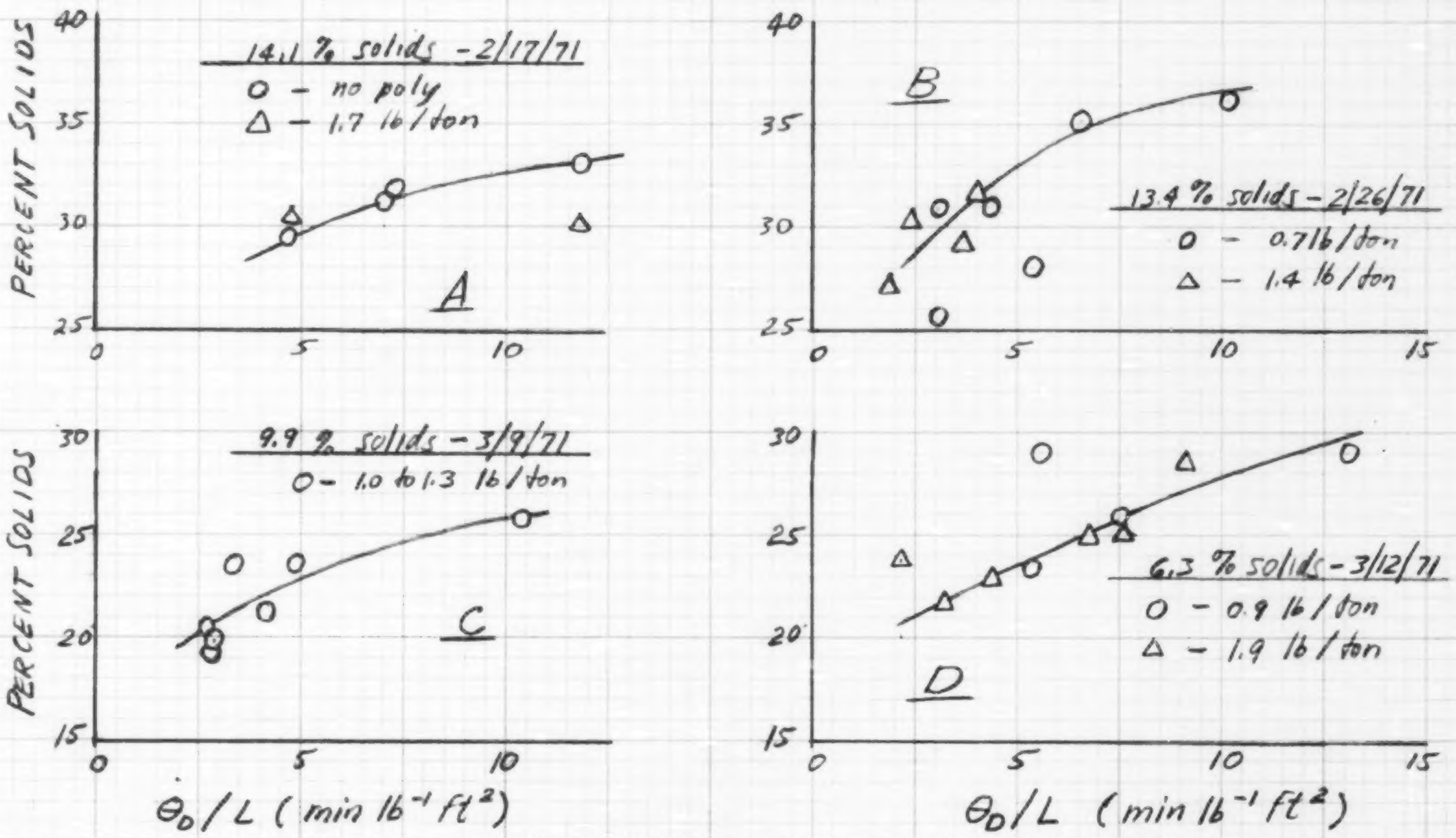


FIGURE 75S CAKE MOISTURE CORRELATION: SOLIDS CONTENT VS. DRYING TIME / LOADING OF FILTER CAKE

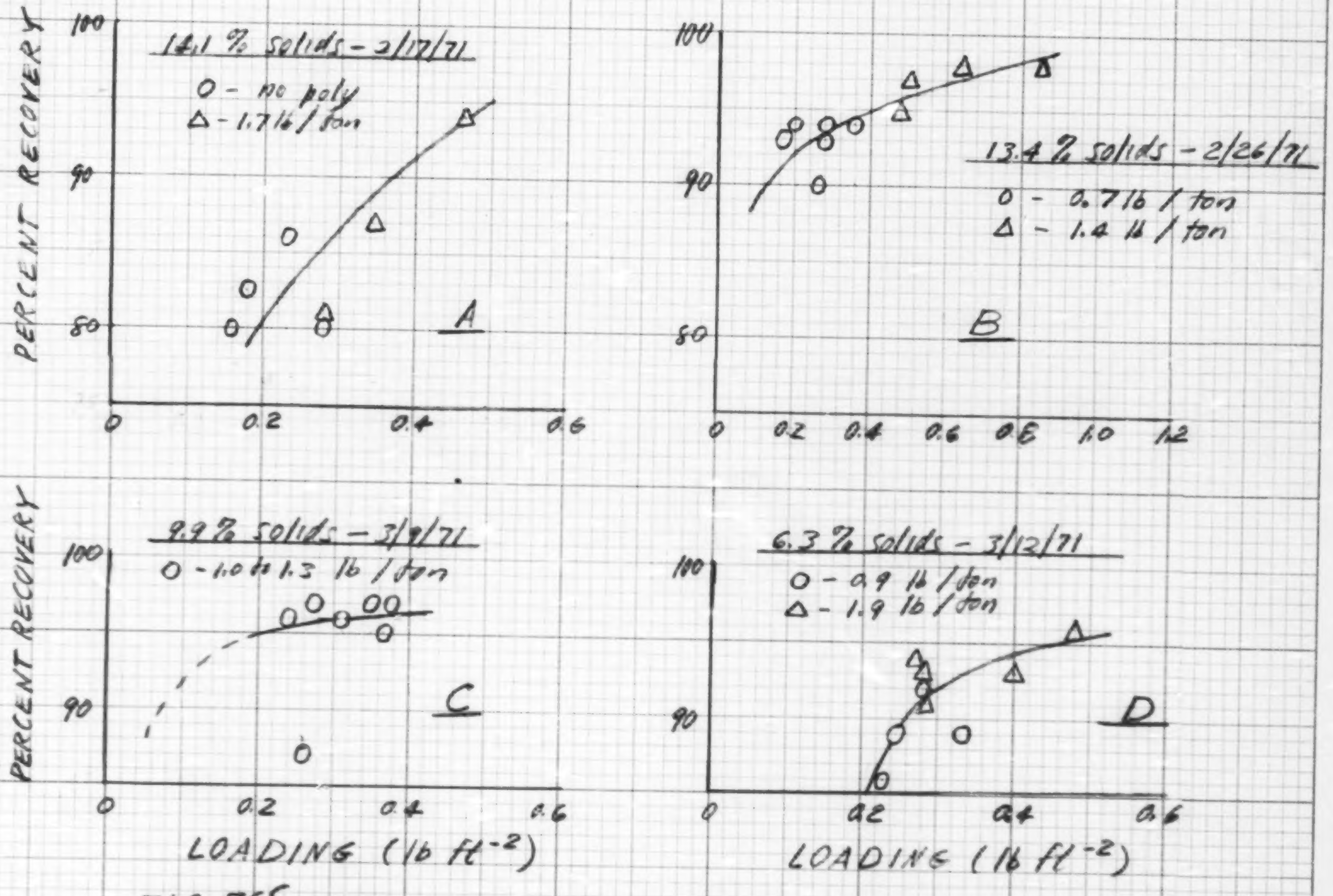


FIG. 765 SOLIDS RECOVERY IN VACUUM FILTER TESTS

APPENDIX I

August 27, 1973

FIELD TRIP REPORT NO. 2

Title: "Dewatering Characteristics of Alum-Primary Sludge at Pomona, California"

Objective: Determine gravity thickening and filtration rates of sludge produced by addition of alum prior to primary clarification at Pomona's pilot plant.

Site Visited: 50 GPM physical-chemical pilot plant at Pomona, California

Persons Contacted: Los Angeles County Personnel:
Leon Directo, Project Engineer
Dr. Ching-Lin Chen, Engineer

EPA Personnel:
Tom Reed, Chemist
James Haskins, Chemist

Field Trip Personnel: S. W. Hathaway

Period of Visit: May 29-June 1, 1973

Author of Report: S. W. Hathaway S. W. Hathaway

APPROVED: J B Farrell

DATE: Aug. 27, 1973

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
NATIONAL ENVIRONMENTAL RESEARCH CENTER
CINCINNATI, OHIO 45268

SUBJECT: Trip Report -- Pomona Field Study DATE July 10, 1973

FROM: S. W. Hathaway S.W. Hathaway

TO: J. J. Convery

THRU: Dr. R. B. Dean
Dr. J. B. Farrell

1. Place Visited: Pomona Pilot Plant
Pomona, California

2. Person Making Trip: S. W. Hathaway

3. Dates of Trip: May 29, 30, 31 and June 1, 1973

4. Purpose of Trip: A. Obtain thickening and dewatering data from the alum primary sludge produced at Pomona.

B. Develop a limited program with LA County so that basic information on sludges can be collected.

5. Persons Contacted: LA County Personnel
Leon Directo, Project Engineer
Dr. Chen

EPA Personnel
Tom Reed, Chemist
James Haskins, Chemist

6. Field Study Report:

Background

At Pomona, California, the EPA's Office of Research and Monitoring have supported research work jointly with Los Angeles County, in which wastewater has been treated with alum as the first step in a physical-chemical system. Sludges generated at Pomona are not dewatered but are returned to the sewer line for transport to the main plant at Juegeres Street, south of the city of Los Angeles. Consequently, the L. A. County's objectives have not included evaluation of sludges; minimal information has been forthcoming on the properties of the sludges produced.

The sludge produced when alum is added for primary treatment is of interest to the Phosphate Sludge Disposal Task Force. Consequently, a field trip was planned with three primary objectives:

a) Obtain as much basic information about sludge settleability and dewaterability as possible during a short visit.
b) Learn the physical layout and facilities, and
c) Develop a limited program with L. A. County staff, so that basic information on sludges can be collected during the course of our joint project.

This field trip report presents the experimental information collected during the short visit to Pomona, May 29 to June 1.

Plant Description

The physical-chemical treatment unit at Pomona uses alum to remove phosphorus and suspended solids. The system is essentially a two tank process. Raw sewage enters the first tank at a constant rate where alum is added at a dose of 22 $mgAL^{+3}/l$. The sewage then enters a rapid mix chamber where an anionic polymer is added to aid coagulation. The sewage then enters a slow mixed chamber for flocculation and exits to the second tank where the solids are settled to the bottom. The tank is rectangular and has a well in the bottom where the sludge is scraped and removed. The sludge is pumped only periodically to allow thickening of the solids. To obtain sludge for the dewatering tests the pump was operated manually and sludge drawn from a sample tube. **The pilot plant wastewater flow rate is 50 gpm.**

Testing Procedures

Gravity Thickening Tests:

A two-liter graduated cylinder equipped with a 1 rpm, three-pronged mixing unit was used to collect data on the settleability of the sludge. The sludge was poured into the unit with or without chemical thickening aid in an effort to separate (thicken) the solids from the liquid. Readings at the solid:liquid interface were taken at intervals for 6 hours to obtain a sludge height vs. time curve. From this settling curve and the solids concentration at each particular height, a flux plot was drawn with percent solids on the abscissa and mass flux on the ordinate. A tangent was then drawn to the curve, giving the desired solids and the flux which could be loaded into the thickener. This procedure was adopted from Professor Dick.* Our particular tests involved four separate thickening units. Sludge in each of the units was treated in the following manner:

1) Sludge with 1.6% solids was diluted with effluent to 0.8% solids.
2) The 1.6% solids sludge was tested in the "as received" state.
3) 2 lbs. of 837-A polymer/ton dry sludge solids was added to 1.6% sludge.
4) 6 lbs. of 837-A polymer/ton dry sludge solids was added to 1.6% sludge.

Eimco Filter Leaf Tests:

The Eimco filter leaf was used in our tests to indicate the filterability of sludge. The Eimco leaf is a 0.1 ft^2 filter, which can be equipped with different types of filter media and vacuum pressure adjustment. The leaf can be operated under specified conditions, such as immersion time and drying time, which simulate the operation of a rotary vacuum filter. After immersion and drying, the filter cake is lifted off the media, dried, and weighed. These data are calculated to give filter yield rates in terms of lb. of dry solids/ft^2-hour.

The work at Pomona first entailed finding the combination of chemicals which gave a thick cake in a specified cycle time, 4 minutes/revolution. Baseline values for chemically conditioning the sludge can be determined by Buchner funnel testing. More detailed information of sludge filterability, such as cycle time, polymer dose, cake solids, and filter yield, is only obtained by filter leaf tests.

A Komline-Sanderson filter leaf was also taken on this field study, because it was supposed to be more indicative of a rotary vacuum coil-filter (which we are operating at the Lebanon pilot plant) than the Eimco leaf. The only difference between the two leaves is that the K-S leaf has a metal filter medium and the Eimco leaf is supplied with cloth media.

To have enough thick sludge for the filter leaf tests it was necessary to settle a large volume (30 gallons) of the sludge as it came out of the clarifier. The initial sludge was only 1% solids, and it was hoped that overnight settling (20 hrs.) would give a thick sludge approximately 4% solids. The result was that the sludge would only thicken to 2.2% because we could not stir the large vessel like we do the lab models. Two series of filter leaf tests were run. The sludge for the first was obtained by adding 1.6 lbs. of 837-A polymer/ton dry solids to 30 gallons of sludge and settling for 2 hours. This process yielded a thickened sludge of 2.2%. The second series of filter leaf tests were performed with alum sludge which was settled for twenty hours and gave a 2.16% sludge for the tests.

---

* Dick, R. I., "Mechanisms of Sludge Thickening," Final Report, EPA Research Grant 17070 DJR (February 1971).

Field Study Results

Gravity Thickening:

To determine the gravity thickening characteristics of the alum primary sludge at Pomona, the laboratory thickening units mentioned in the procedure were operated for 24 hours. A flux curve was drawn for each of the four tests based on settling velocity and sludge solids concentration. After 20 hours of settling, the final reading at the solid:liquid interface was taken and plotted on the settling velocity curve. As a final point of assumed zero velocity and, therefore, zero flux, the 20 hr. reading shows the maximum solids concentration possible for that particular test. Detailed graphs concerning initial settling curves and settling velocity plots are shown in attachments a, b, c, d. Since all of the tests yielded at least 4% solids after overnight thickening, I calculated the loading rates on the basis of this value. Under batch thickening conditions the 1.6% alum sludge without chemical aid could be loaded into a thickener at a rate of 6.6 lbs/ft^2-day (see Figure 1) and removed at approximately 4% solids. Diluting the sludge had a deleterious effect. Figure 2 shows that 2.7 lbs/ft^2-day could be added to a thickener and removed at 4% if the sludge is diluted prior to thickening. Polymer addition to the sludge prior to thickening shown in Figure 3 improved the loading considerably. By adding 2 lbs. polymer/ton dry solids, the thickener loading was increased to 20 lbs/ft^2-day. Figure 4 shows that 6 lbs. polymer/ton dry solids increased the loading to 72 lbs/ft^2-day and could be removed at 4% solids.

Filter Leaf:

Testing with a filter leaf is generally a difficult task to complete, because there are so many variables to optimize. A preliminary set of filter leaf tests was made in an attempt to minimize the number of tests required. Previous Buchner funnel tests completed before I arrived at Pomona gave a chemical conditioning baseline of 1% to 2% $FeCl_3$ according to the sludge solids. This concentration of $FeCl_3$ was sufficient to increase the filter rate by a factor of two. Since this increase was not great, I decided to use about 3% $FeCl_3$ for the filter leaf tests. My experience had been that $FeCl_3$ alone is not adequate for producing a cohesive cake. Consequently, lime was added to give body to the cake and improve the efficiency of discharge. At a lime dose of 7%, 3% $FeCl_3$ and a 4 minute cycle time, filter yields were in the range of 1.07 to 1.53 lbs/ft^2-hr. Detailed results are presented in Table 1. The addition of 14% lime and no $FeCl_3$ gave an average yield of 1.07 lbs/ft^2-hr.

Following the preliminary tests mentioned above, a larger series of leaf tests gave more detailed information about cycle time, polymer dosage, and cake solids. Detailed results are presented in Table 2. Figure 5 shows the effect of increases in polymer dose on the filter yield (corrected for 12% lime dose) for 2, 4, and 6 minutes/revolution. Because of limited time only two doses of polymer were investigated. The graphs are, therefore, somewhat deficient, but the general trend of increased yield is the result of adding more polymer to the sludge. The effect is dramatic at the 2 min/rev cycle, where a polymer dose of 2.4 lbs/ton dry solids caused a filter yield of 1.8 lbs/ft^2-hr. The opposite effect was noted (Figure 6) when the cake solids were calculated. Increasing polymer doses made the cake solids lower. When these cake solids data are plotted against drying time per unit of loading (Θ_D/L - min $lb^{-1}ft^2$), a good correlation is achieved (see Figure 7). It appears then that the cause of the increased moisture content is not the presence of polymer, but rather that the increased polymer dose increases filter yield and reduces drying time per unit of sludge loading.

In tests where polymer was used without lime, the cake solids averaged 2-4% lower than when polymer and lime were used together, and the cake did not release well from the filter media. In general, the filtrate was clearer when lime was not used for conditioning, but even with lime the suspended solids concentration was only 400 mg/l. One observation was of particular interest. High polymer doses were excellent (visually) for causing efficient separation of liquid and solid. Coagulated sludge was drawn up onto the filter media, but would drop off when the leaf was withdrawn from the sludge.

Approximate measurements indicated that cakes were thicker than 1/8 inch, but calculated values were substantially below this figure (see Table 2). Nevertheless, release was good except as noted above.

Most of the filter leaf tests were done with Eimco test leaves. To get an idea of how well a coil filter would dewater alum sludge, the Komline-Sanderson leaf was used in three tests. Table 3 shows that the yield is about the same as the Eimco leaf shows in Table 2 at the 4 min/rev cycle. One difference is the cake solids. An increase in polymer dose did not seem to affect the cake solids.

Discussion of Results

Alum sludge produced at Pomona seems to be typical if compared to the dewatering of alum sludges produced elsewhere. Filter yield values were low (1.8 lbs/ft^2-hr highest obtained) for the chemical dose ranges examined. Perhaps with higher doses the yield could have been improved. The usual problem of obtaining thick sludge for leaf testing was with us again and could not be solved without larger scale thickening equipment. A sludge thickener must be stirred slowly to obtain at least 3% solids. The results of filter leaf tests presented in this report are biased because the solids concentration in the sludge was only 2.2%. A choice of two conditions gave the best results in the filter leaf testing. A 2 minute/revolution cycle gave a higher yield (1.8 lbs/ft^2-hr) than the 4 min/rev cycle (0.93 lb/ft^2-hr), but the 4 min/rev cycle gave a higher cake solids (19.7%) than the 2 min/rev cycle (15.6%). The method chosen for sludge disposal is the only criterion for the decision of 2 or 4 minute cycle times.

An important piece of data in this report shows that Pomona's alum sludge can be thickened reasonably well without chemical conditioning. However, with polymer conditioning the thickening characteristics of the alum sludge are remarkably good.

TABLE 1

Summary of Eimco Leaf Tests * 5/30/73

Sludge thickened to 22,090 mg/l

2 hr. settling time with
1.6# poly/ton DS added
to initial sludge to
aid settling

Cycle Time	% Lime	% $FeCl_3$	% Cake Solids	(lbs/ft^2-hr) Corrected Yield
4	7	2.7	20.6	1.32
4	7	2.7	21.9	1.53
4	7	2.7	16.3	1.09
4	7	2.7	18.6	1.07
4	13.6	0	20.4	1.09
4	13.6	0	13.7	1.05

* Percent immersion was 33%.

TABLE 2

Summary of Eimco Leaf Tests* 5/31/73

Sludge thickened to 21,160 mg/l

Overnight settling --
no chemical aid

Cycle Time	% Lime	lbs. poly/ton DS**	% Cake Solids	(lbs/ft^2-hr) Corrected Yield	Thickness (in.)***
2	0	1.4	18.3	1.07	0.028
2	0	1.4	19.9	1.08	0.028
2	0	2.4	12.6	1.13	0.030
2	0	2.4	14.3	1.17	0.039
2	0	3.0	16.5	0.89	0.035
2	0	3.0	10.3	1.33	
2	12	1.4	16.4	1.44	0.038
2	12	1.4	17.8	0.86	
2	12	2.4	14.7	1.78	0.047
2	12	2.4	16.4	1.80	0.048
4	12	1.4	20.7	0.78	0.042
4	12	1.4	20.8	0.62	0.033
4	12	2.4	19.7	0.92	0.049
4	12	2.4	19.7	0.94	0.050
6	12	1.4	22.3	0.66	0.053
6	12	1.4	20.8	0.72	0.058
6	12	2.4	19.5	0.70	0.056
6	12	2.4	18.9	0.89	0.071

*Percent immersion was 33% for all tests.

**In all cases, the polymer was Type 837-A, an anionic polymer supplied by American Cyanamid.

*** Thickness was calculated assuming 20% cake solids, wet cake density of 75 lb/ft^3.

TABLE 3

Summary of Komline-Sanderson Leaf Tests 5/31/73

Cycle Time	% Lime	lbs. poly/ton DS	% Cake Solids	(lbs/ft^2-hr) Corrected Yield
4	10	1.4	20.8	0.86
4	0	1.4	20.8	0.64
4	0	2.4	25.8	0.72

FIGURE 1

FLUX PLOT
ALUM SLUDGE
GRAVITY THICKENED
NO CHEMICAL AID

5/29/73

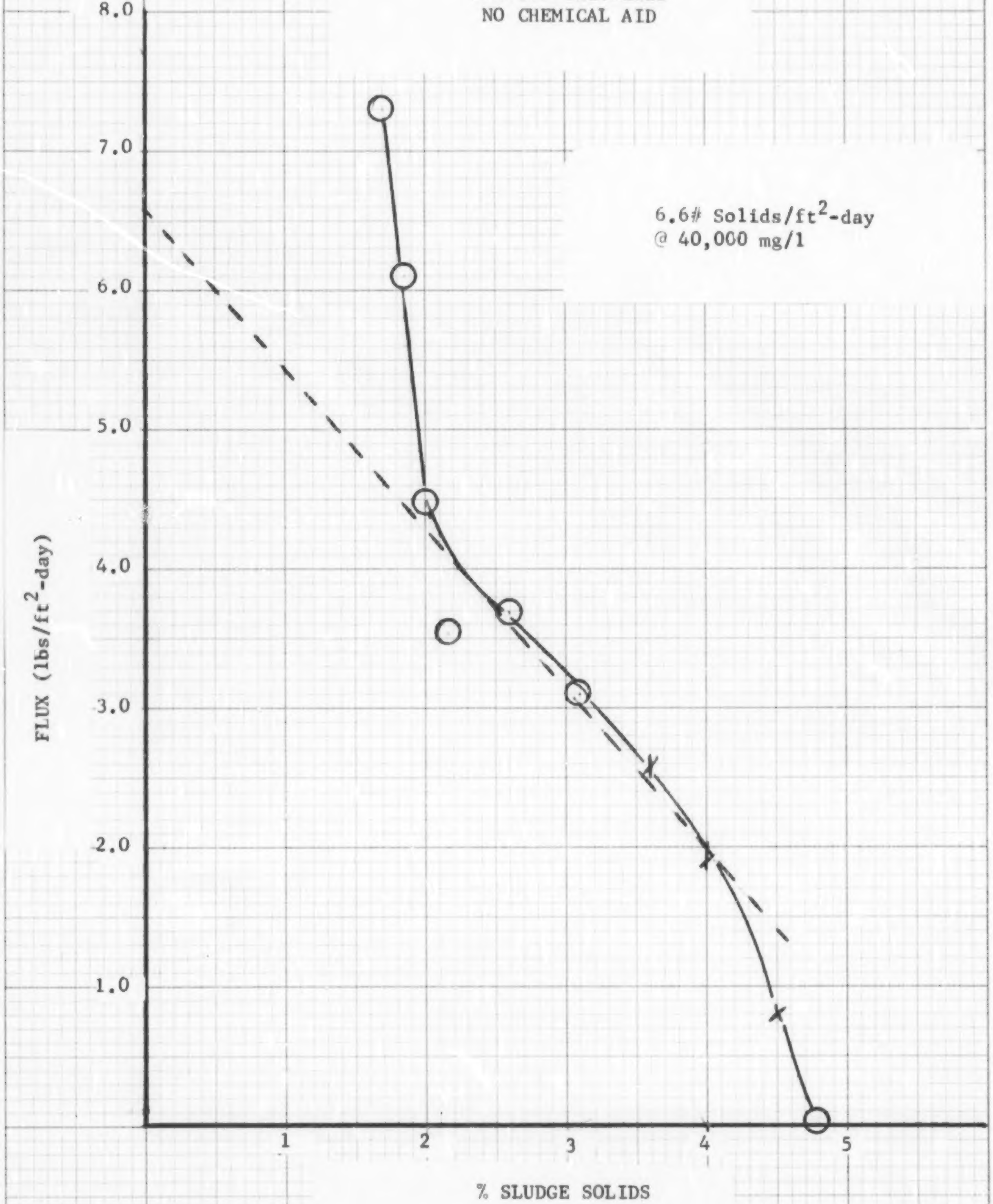
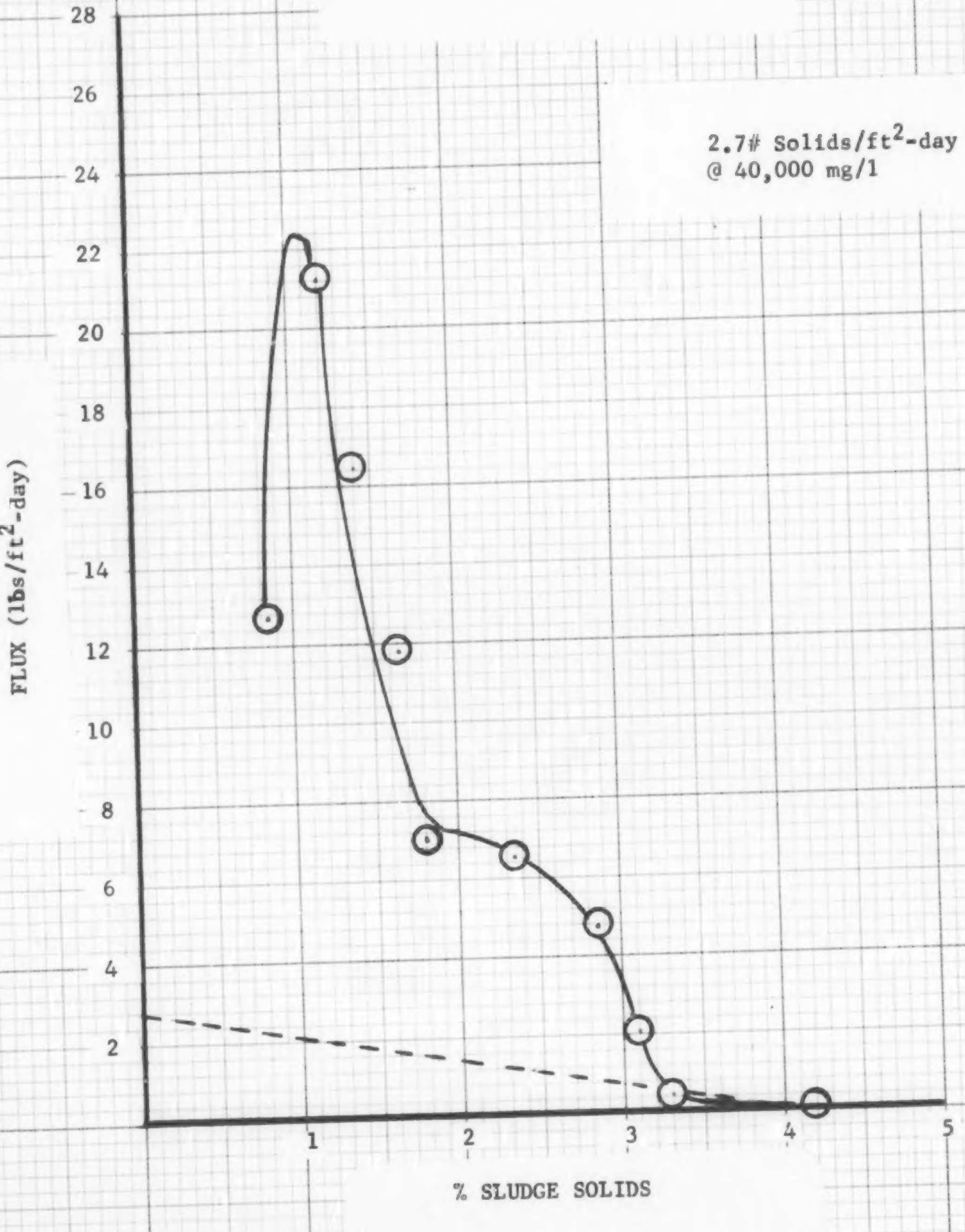


FIGURE 2

FLUX PLOT
ALUM SLUDGE
NO CHEMICAL
DILUTED WITH EFFLUENT
1:1

5/29/73



2.7# Solids/ft^2-day
@ 40,000 mg/1

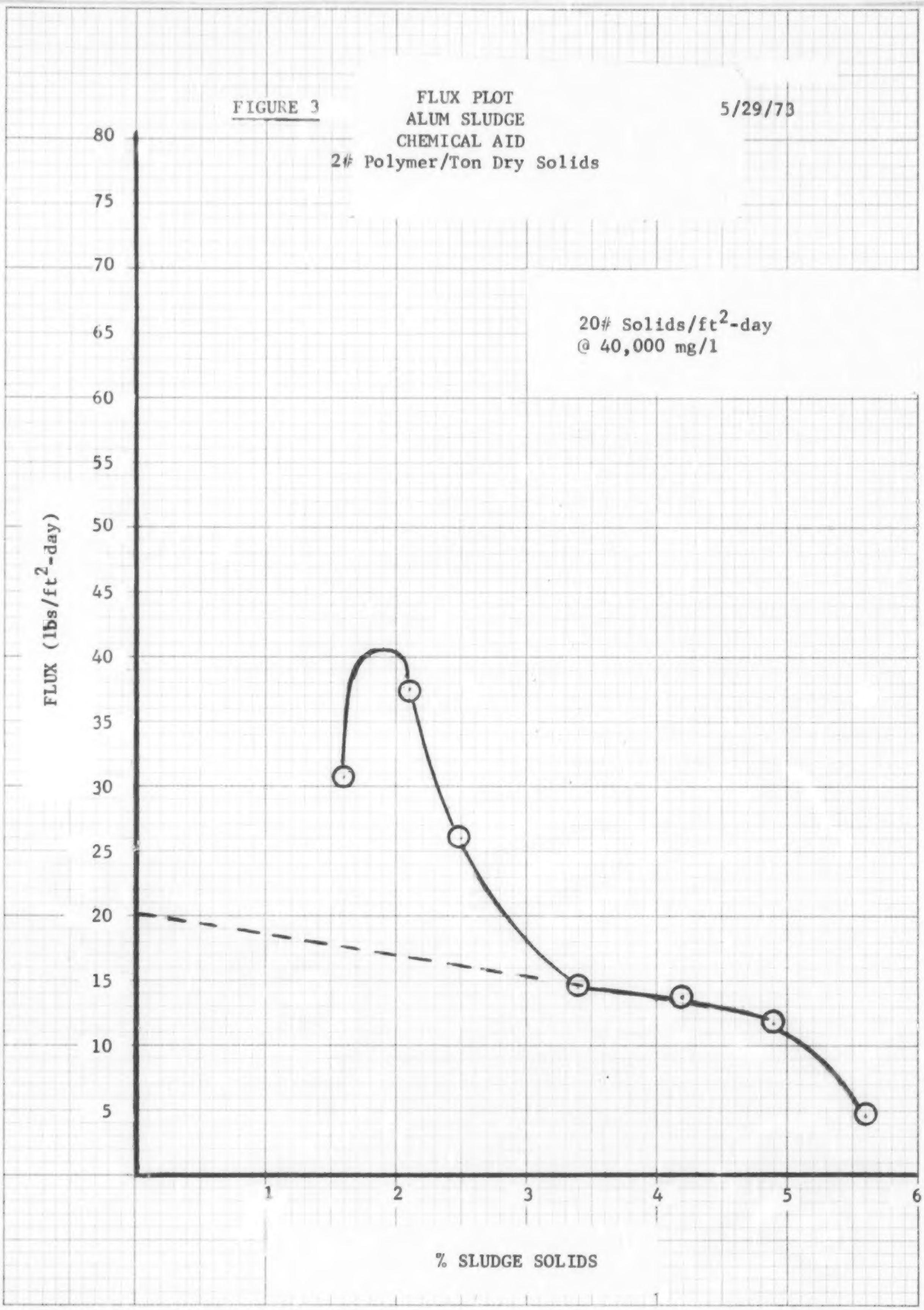


FIGURE 3

FLUX PLOT
ALUM SLUDGE
CHEMICAL AID
2# Polymer/Ton Dry Solids

5/29/73

FIGURE 4

FLUX PLOT
ALUM SLUDGE
CHEMICAL AID
6# Polymer/Ton Dry Solids

5/29/73

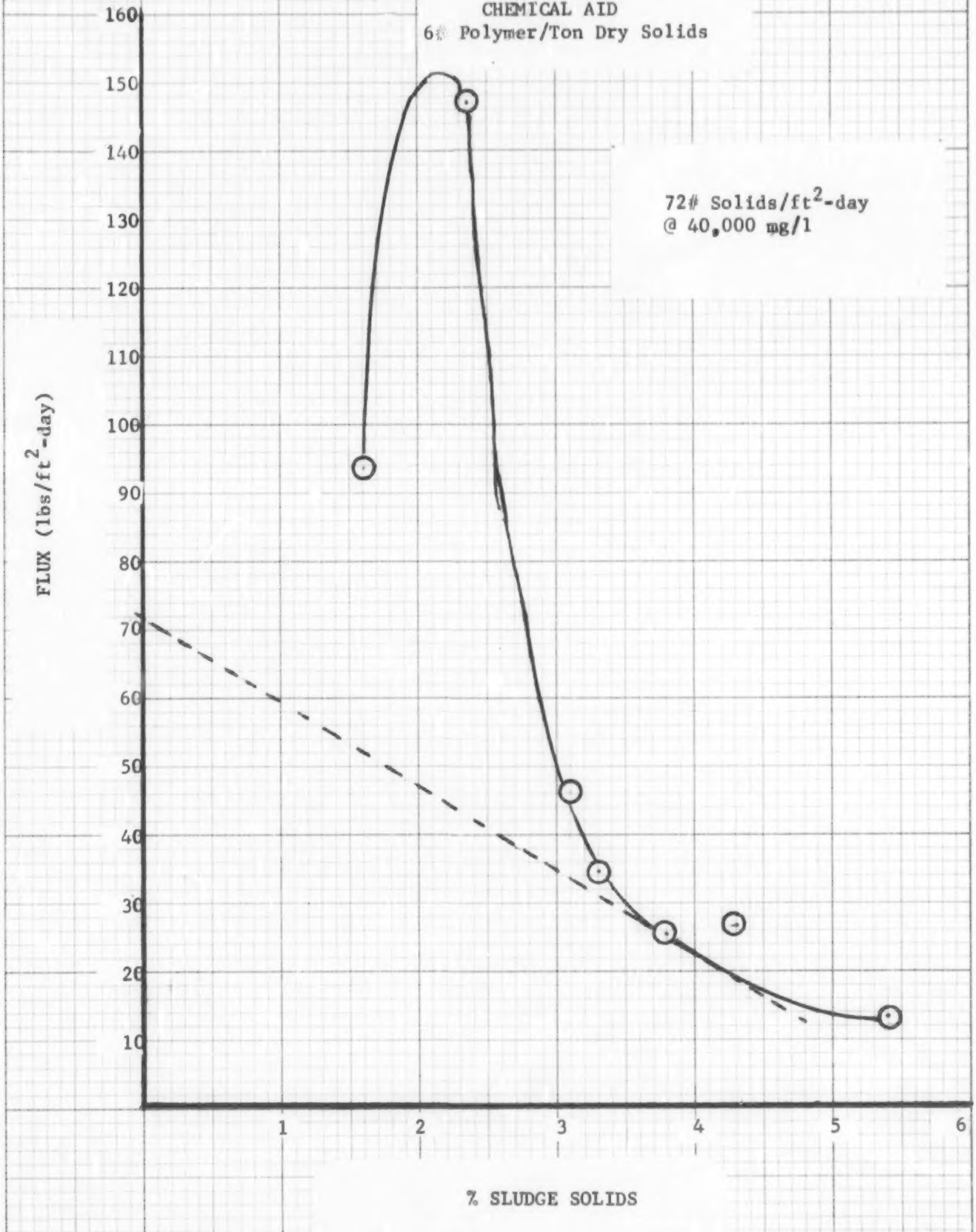


FIGURE 5

POLYMER DOSE & RESULTANT YIELD
FOR 2, 4, & 6 MINUTE CYCLES

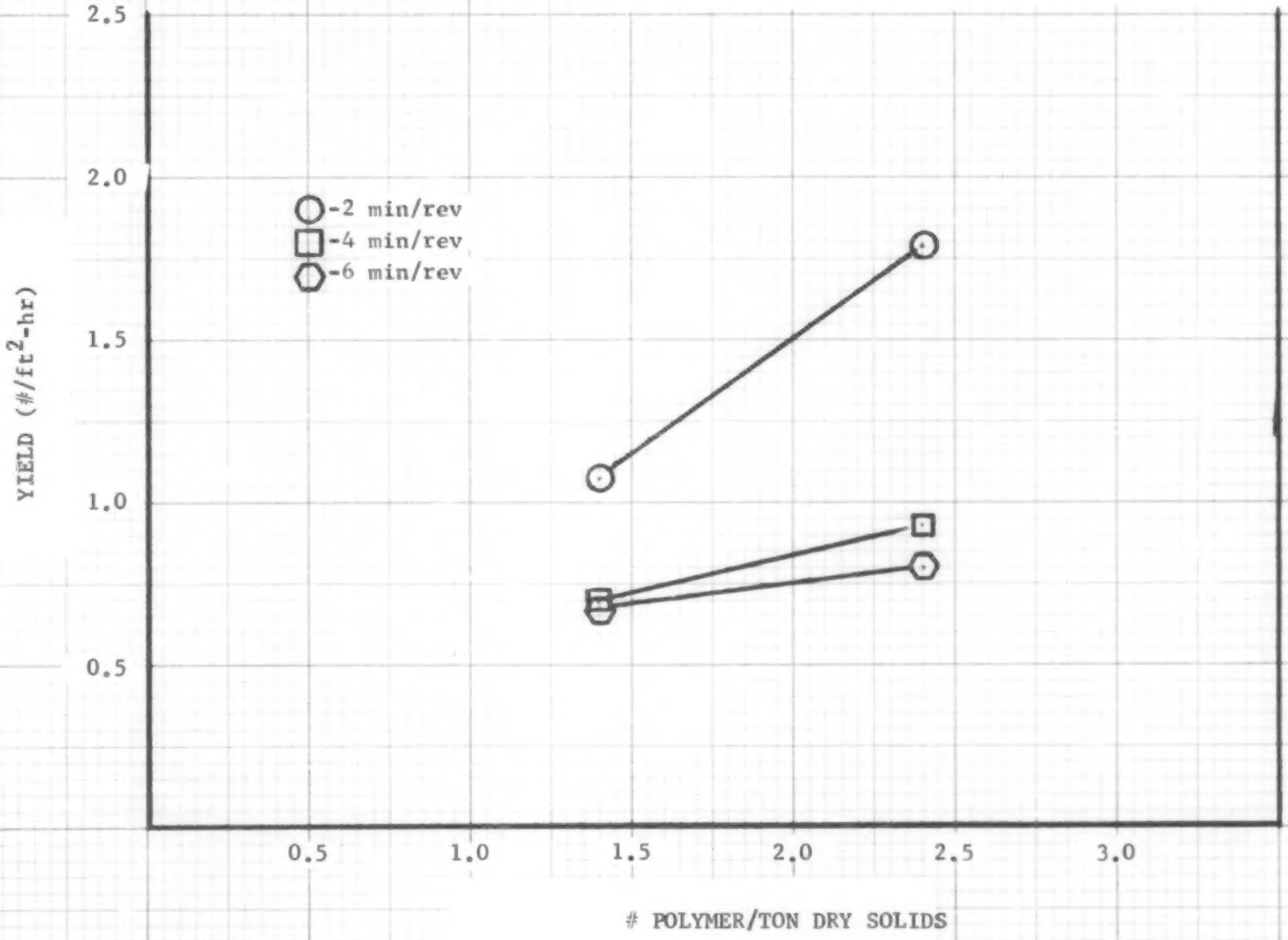
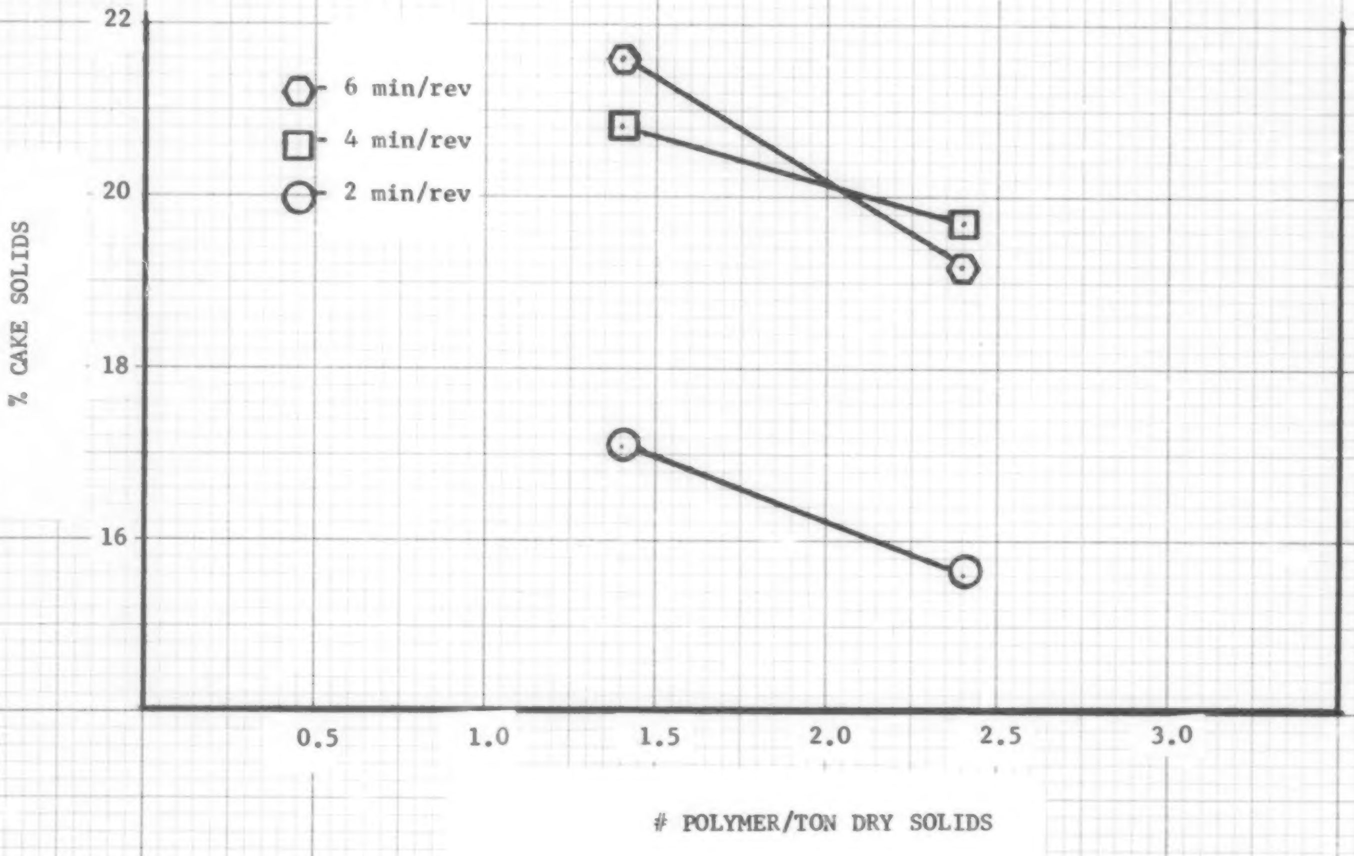


FIGURE 6

POLYMER DOSE & RESULTANT CAKE SOLIDS
FOR 2, 4, & 6 MINUTE CYCLES



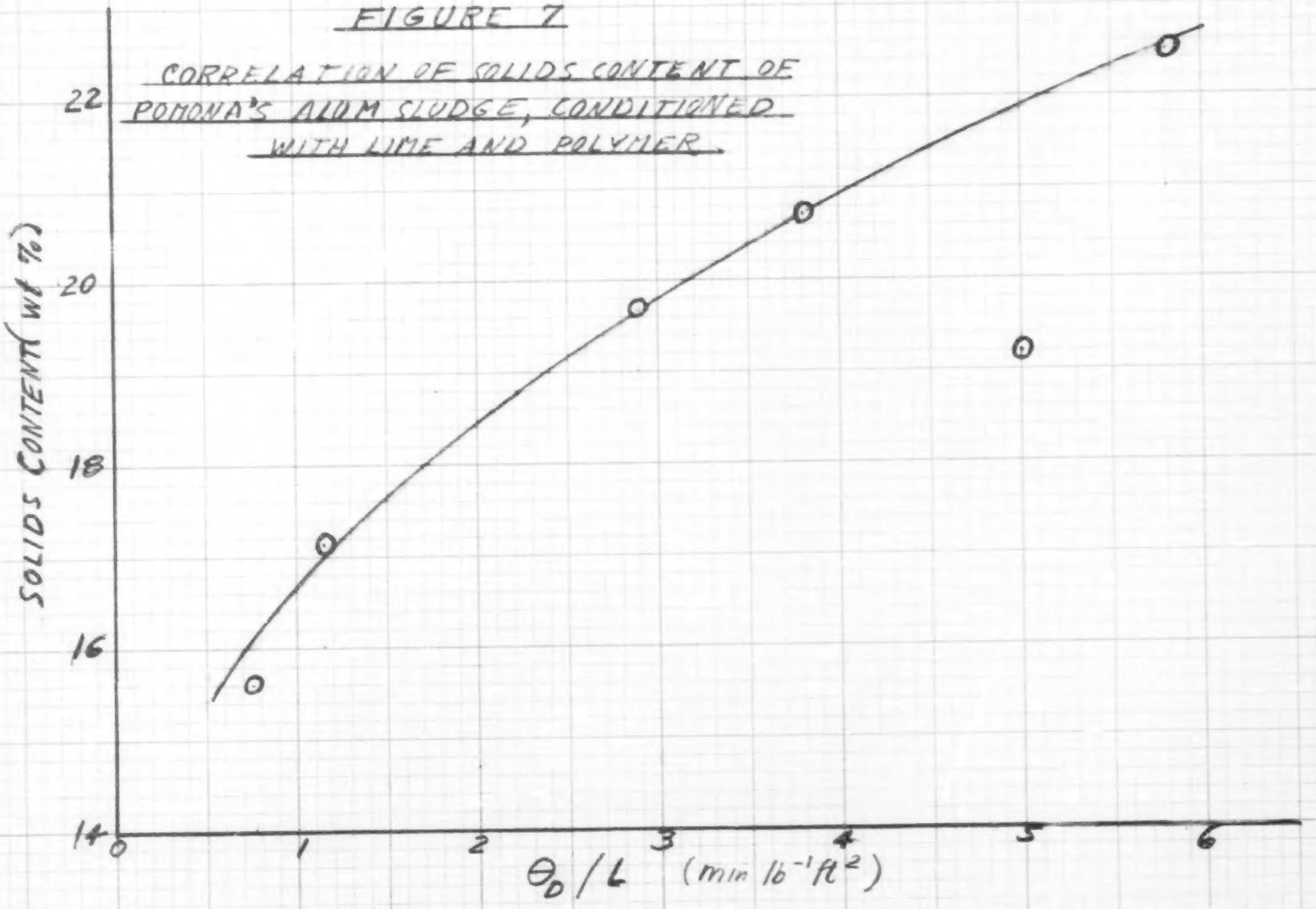
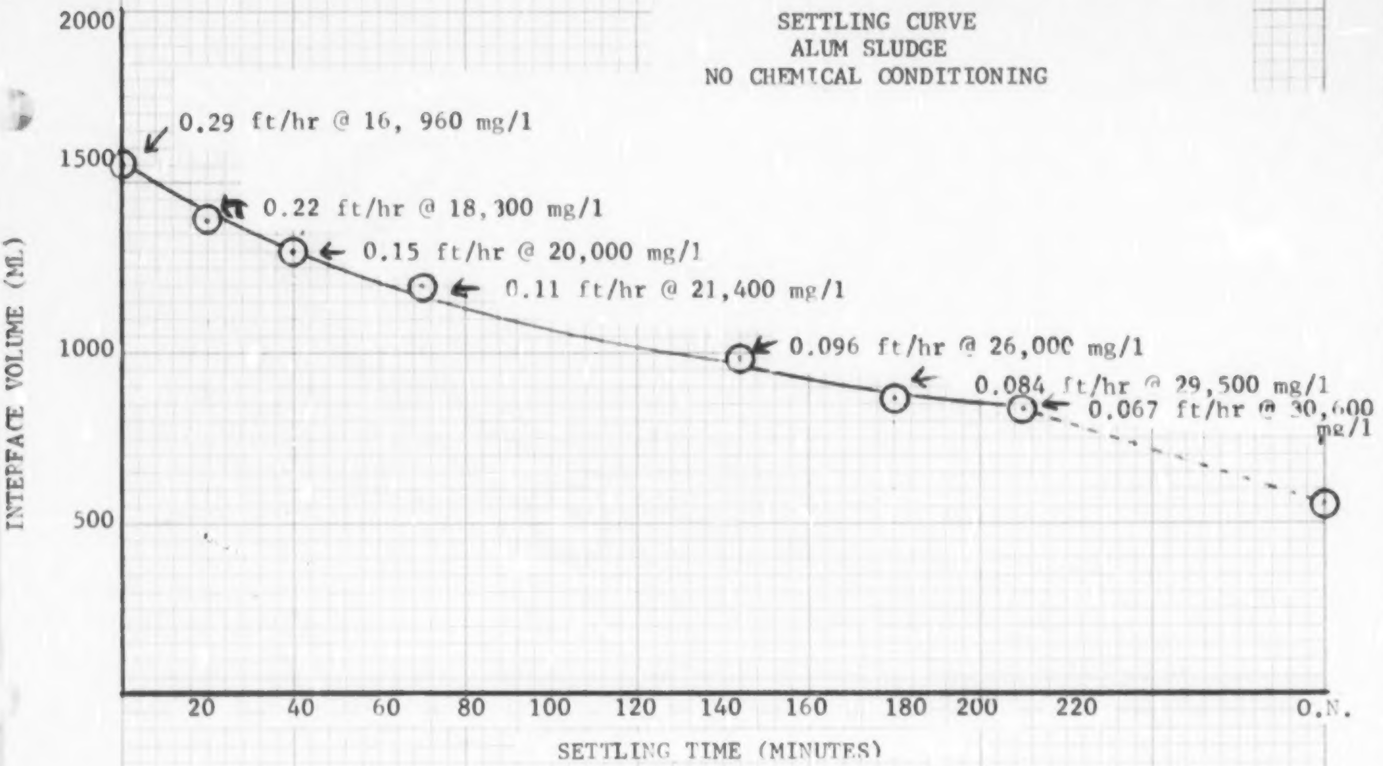
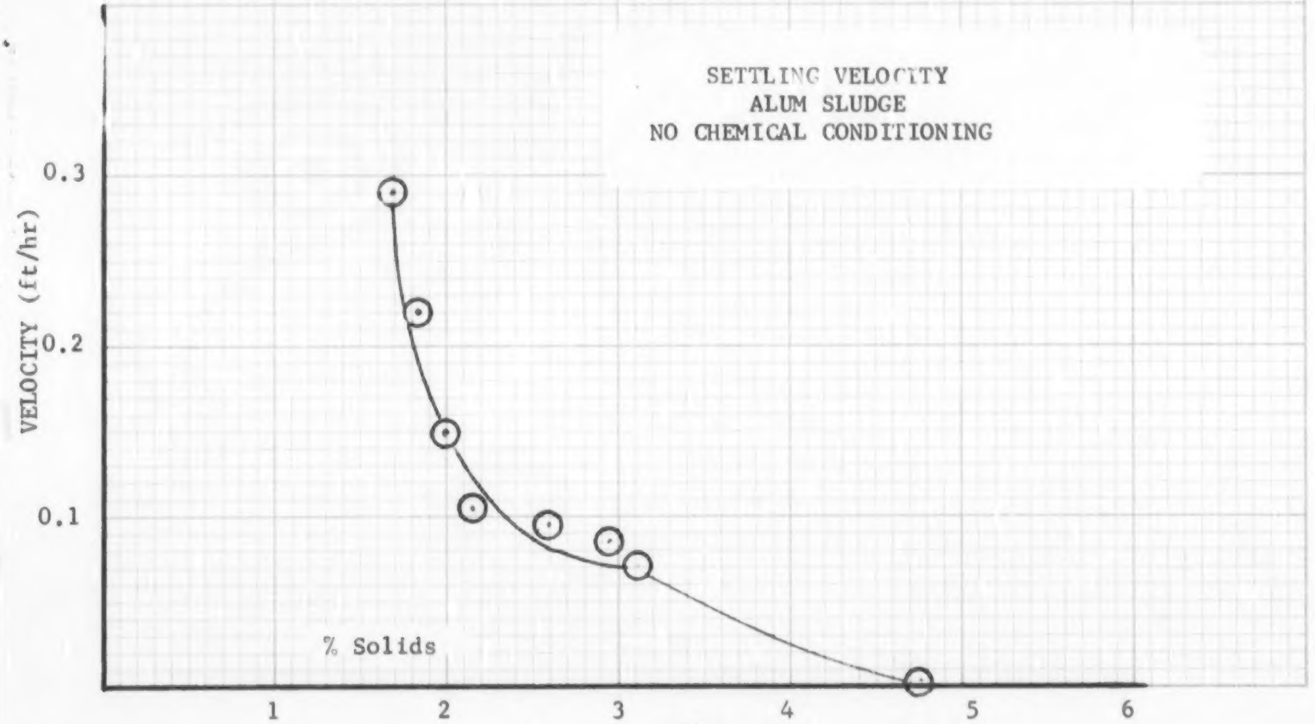


FIGURE 7

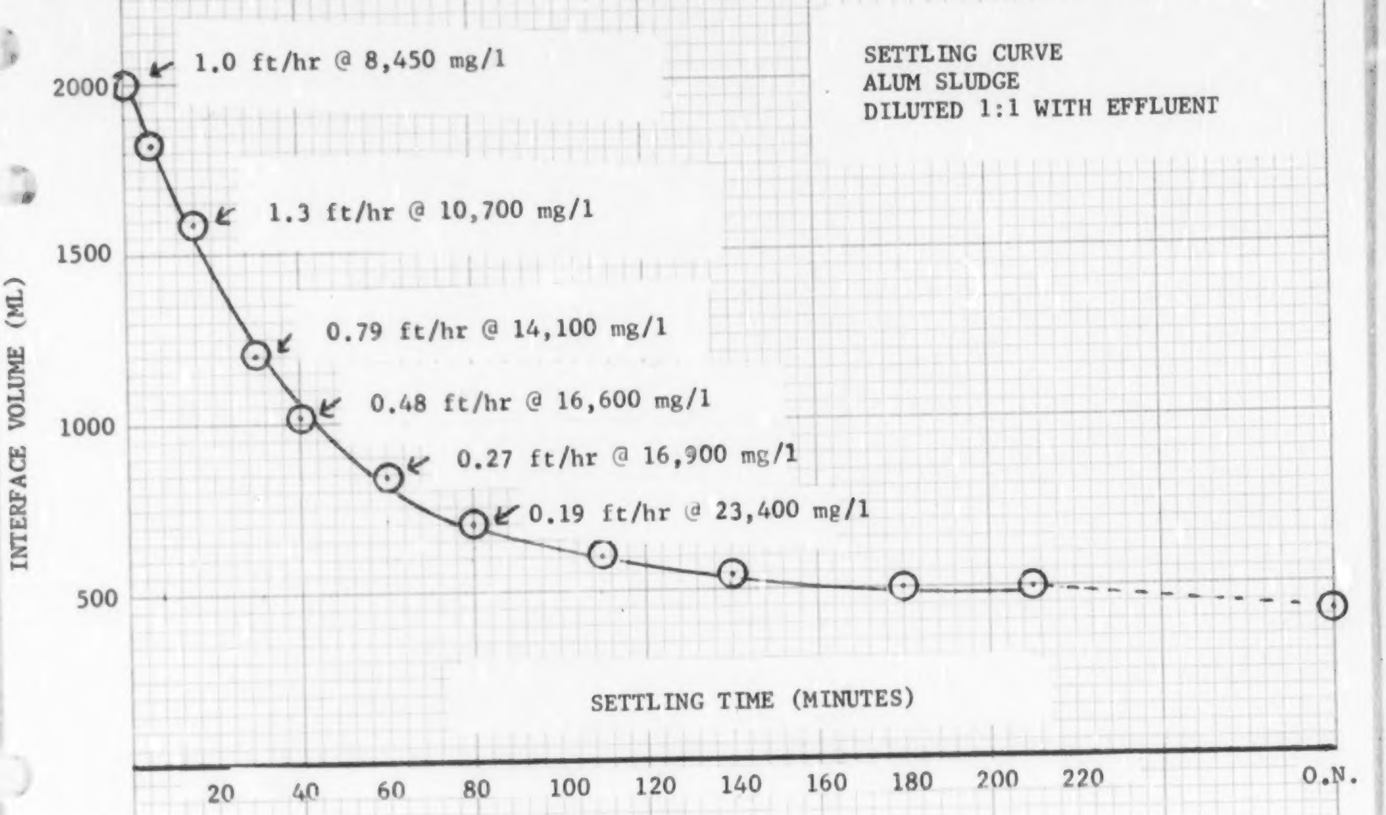
CORRELATION OF SOLIDS CONTENT OF POMONA'S ALUM SLUDGE, CONDITIONED WITH LIME AND POLYMER.

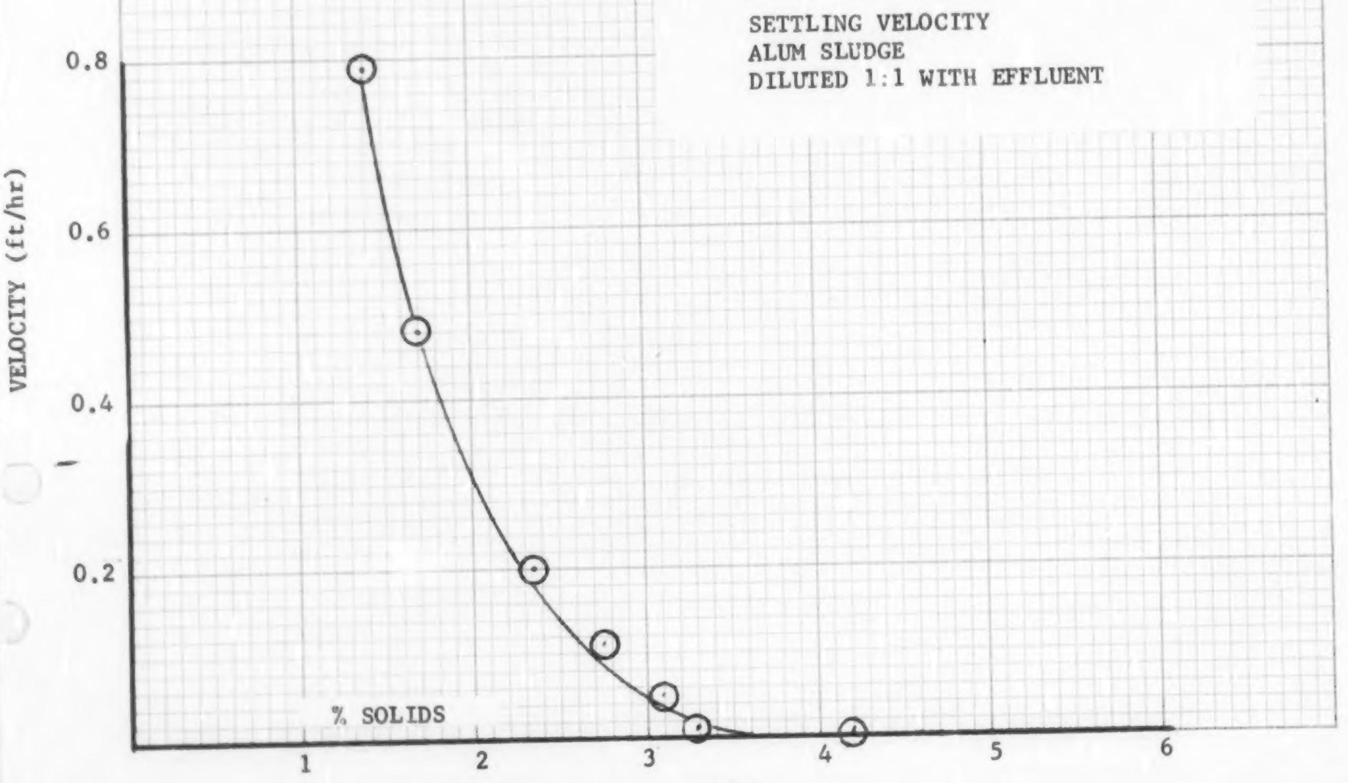
ATTACHMENT a



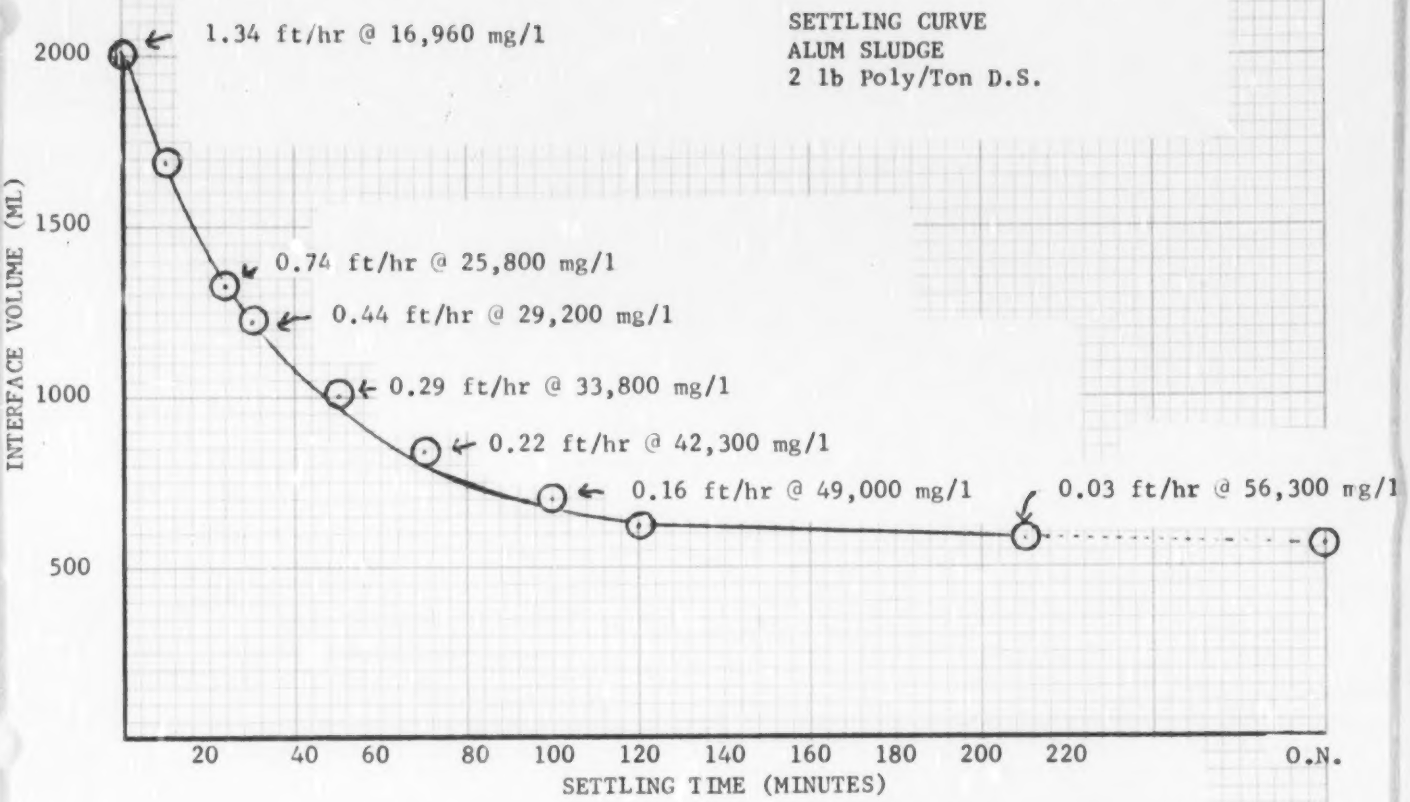


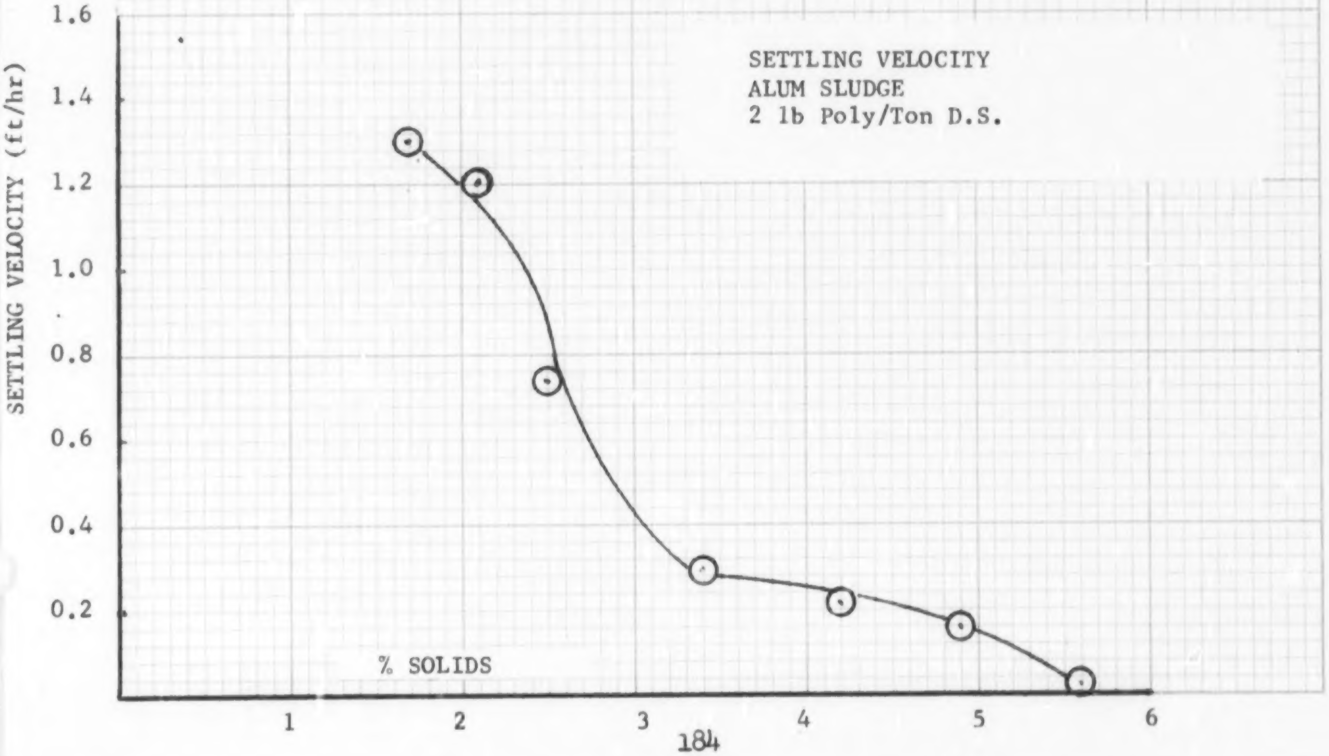
ATTACHMENT b


SETTLING CURVE
ALUM SLUDGE
DILUTED 1:1 WITH EFFLUENT

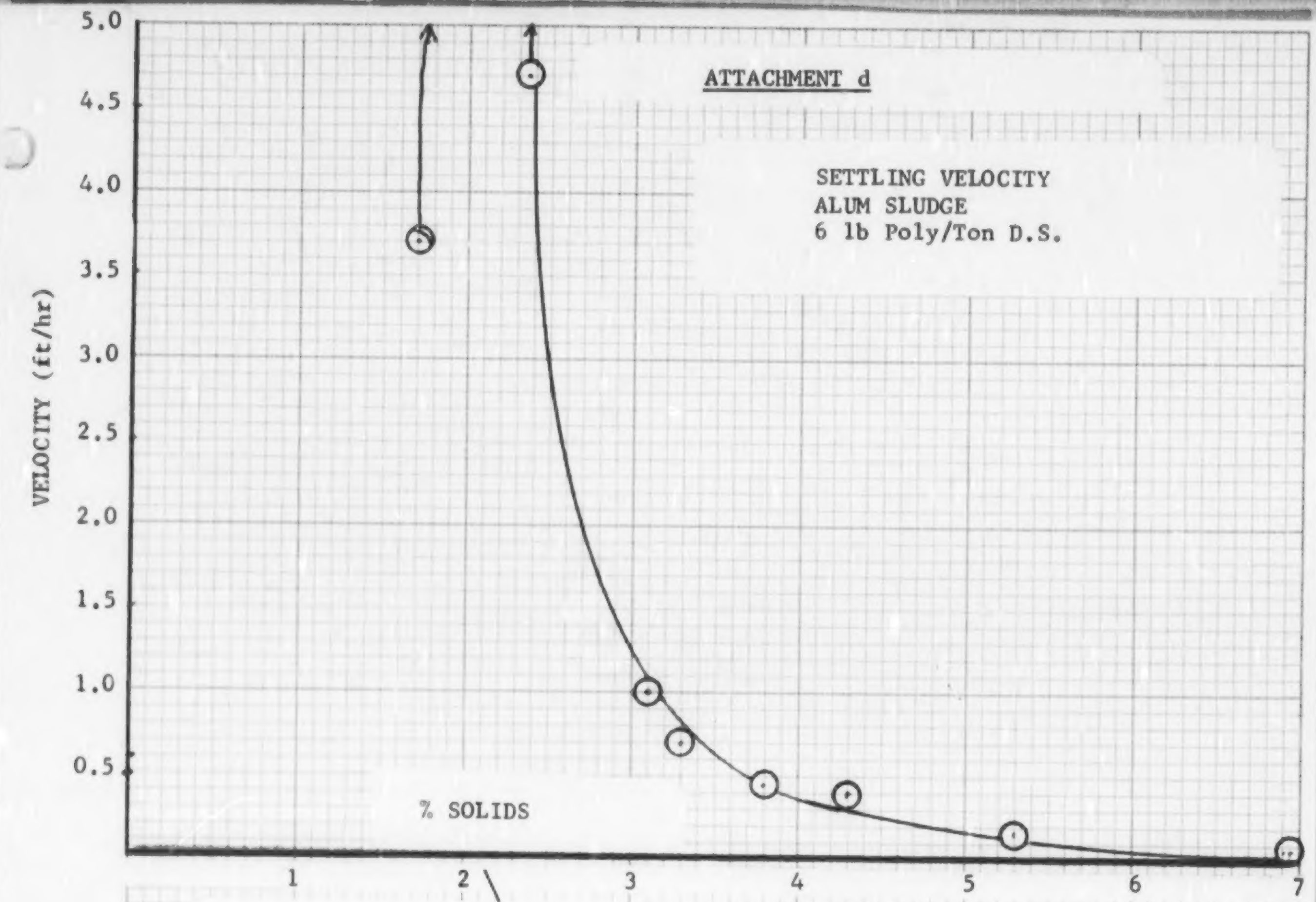

SETTLING VELOCITY
ALUM SLUDGE
DILUTED 1:1 WITH EFFLUENT

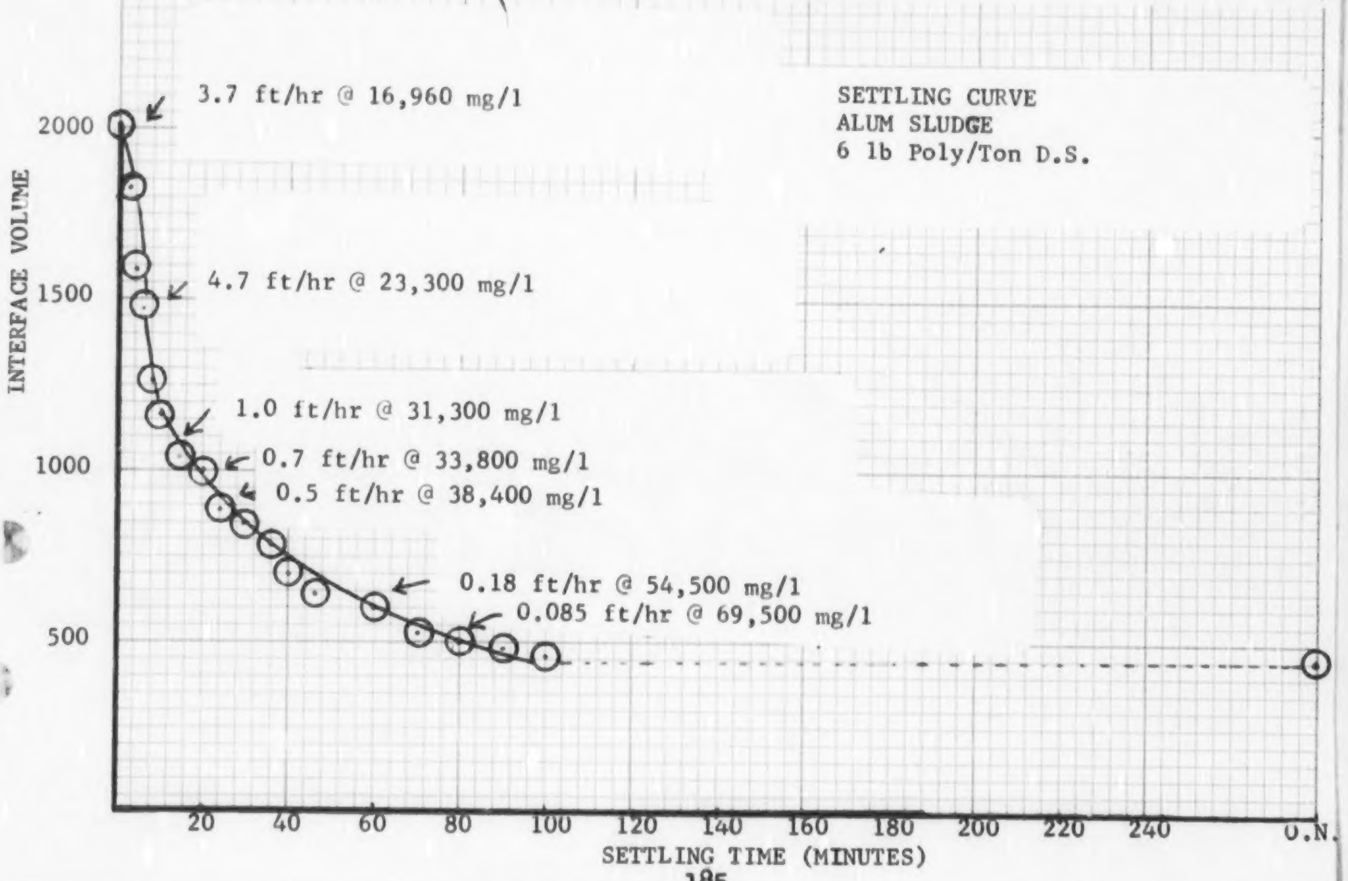
ATTACHMENT c





ATTACHMENT d





APPENDIX J

FIELD TRIP REPORT NO. 1

Title: "Characteristics of Alum Sludge from a Trickling Filter Plant"

Objective: Determine the characteristics of sludge generated by alum addition just prior to the clarifier in a trickling filter plant, and mixtures of this sludge with primary sludge.

Site Visited: 5.0 MGD Wastewater plant at Chapel Hill, North Carolina

Persons Contacted:
Dr. Jim Brown, Director, UNC Wastewater Research Center
Dr. Don Francisco, Deputy Director, UNC Wastewater Research Center
Dr. Linda Little, Project Director, UNC Wastewater Research Center

Field Trip Personnel:
Mr. S. Hathaway, Supervisor
Mr. O. Grant
Mr. J. Burden

Period of Visit: September 5-9, 1972

Author of Field Trip Report: S. Hathaway

Approved: J. B. Farrell

BACKGROUND

The most effective and reliable means of removing phosphate from wastewater is by chemical addition. The choice of chemical and its point of application depend on the details of the specific situation. For an existing trickling filter plant, the choice is often made to add a chemical, such as alum, just prior to final clarification.

The wastewater treatment plant at Chapel Hill, North Carolina, which is a high-rate trickling filter plant, has been dosing half of its wastewater flow with alum prior to final clarification in an experimental program. The plant is ideally arranged for comparative sludge studies (see below). Consequently, a field trip was planned in which a group from the Advanced Waste Treatment Laboratory visited the Chapel Hill facility for three days, and conducted thickening and filtration tests on their sludge streams.

PLANT DESCRIPTION

The wastewater treatment plant at Chapel Hill, N. C., is supervised by staff members of the Civil Engineering Department of North Carolina State University.*

The treatment plant is a 5 MGD primary and high-rate trickling filter system. A schematic diagram of the plant is presented in Figure 1. The raw sewage enters the plant and is split to two duplicate plants. Since these are high-rate trickling filters, a substantial proportion of the total flow leaving the trickling filter (approximately 120 percent) is recycled back to the primary clarifier.

The remainder of the trickling filter effluent passes to the final clarifier. Sludge settled in the final clarifier is combined with influent sewage just before it enters the primary clarifier. All process flow streams of the two duplicate plants are kept separate from the other. Sludges are kept separate up to the point where they enter the anaerobic digester.

Sludge is digested in a two-stage digester, and dewatered either by running the sludge to drying beds or by means of a Bird solid-bowl (conveyor type) continuous centrifuge.

*Dr. Jim Brown, Director; Dr. Don Francisco, Deputy Director, UNC Wastewater Research Center.

The division of the plant into two nearly identical units makes the Chapel Hill plant a unique facility for full-scale experimentation. One unit can serve as a control so that valid comparisons can be made of the effect of changes in process variables in the other unit. This has been a specific objective of the North Carolina State staff in recent plant expansions. The facility is used for student training, graduate research, and has received support from EPA's Grant Program. The plant is well-instrumented, sophisticated analytical equipment is available, and analytical data are routinely collected on process streams.

TESTING PROCEDURES

Various specialized equipment for dewatering and thickening was taken on a station wagon for test work at the treatment plant site. In three days of testing, the following schedule was completed:

Day 1 - Polymer screening and determination of dosing optimum required a considerable number of Buchner funnel tests and solids analysis. Specific resistance values were obtained for polymer conditioned sludges. Some preliminary filter leaf tests without polymer conditioning were carried out.

Day 2 - Selected specific resistance and polymer dosing data were obtained. Filter leaf testing was conducted at optimum cycle time and polymer dose levels to determine yields for all sludges involved.

Day 3 - Filter leaf testing was continued, along with thickening tests for all sludges. Stirred and unstirred thickening were compared, and some tests of polymer conditioning to improve thickening were conducted.

There were four sludges used in the thickening and dewatering tests: (1) primary mixed with the trickling filter sludge from the control system (p-TF-C), (2) primary mixed with the alum trickling filter sludge for the alum-dosed system (P-TF-A), (3) trickling filter sludge from the control system (TF-C), and (4) trickling filter sludge from the alum-dosed system (TF-A). The appearance and physical nature of the mixed primary sludges from the two systems were indistinguishable to the eye even though one was mixed with the alum portion of the trickling filter sludge.

Polymer Screening Tests. A series of tests were carried out, using Buchner funnels, in order to establish suitability of polymers for sludge conditioning and their approximate dosage levels. Four polymers, selected on the basis of previous testing, were taken to the Chapel Hill plant site for use as sludge conditioners. Two anionic polymers (Purifloc A-28 and Magnafloc 837 A) and two cationic polymers (Calgon WT-2660 and Purifloc 41) were added to the various sludges in low and high doses to determine the best conditioning agent for a particular sludge. The solutions of polymer were made up to 1.0 percent concentration.

To evaluate the conditioning effect of polymers, Buchner funnel testing consisted of filtering a 100 ml sample until 50 ml of filtrate were collected in each case and the time required for that 50 ml to be filtered recorded.

Specific Resistance Measurements. All specific resistance measurements were made with the sludge conditioned with polymer. Compressibility was measured by determining specific resistance (Buchner funnel test) at different pressures. From this data the slope of the log p vs log specific resistance gives the compressibility of the conditioned sludge.

Filter Leaf Testing. Preliminary filter leaf tests determined that polymer conditioning was necessary for all sludges. After polymer conditioning, the sludges were filtered on the leaf apparatus under various cycle time conditions. The selection of the polymer to be used for a particular sludge was based on results of the Buchner funnel tests performed prior to the filter leaf tests.

Thickening Tests. Thickening tests were carried out following Eimco's test procedure which utilizes a 2-liter graduated cylinder equipped with a slow-speed stirrer. Only the trickling filter and alum trickling filter sludges were thickened. The sludge sample was added to the graduate and mixed thoroughly. The 2-rpm mixer was then placed in the sludge and started up, to commence the settling test. Readings of sludge and supernatant levels were taken every 5 minutes and recorded over a two hour settling period.

RESULTS OF TESTING

At the time of our visit, the split of flow between the control

(C) and alum-dosed (A) systems was 50:50. Alum was being dosed at the rate of 180 mg/l (16.2 mg/l Al) to the A-system. Sludge removal from the final clarifier of both systems was continuous. No sludge blanket built up; consequently, the sludge was quite dilute. We had to build a continuous thickener to obtain more realistic sludge for filter leaf and thickening tests.

On the first day of our visit, there was a plant upset. A main pumping station broke down for several hours which actually caused a shutdown of the plant. When the plant flow was restored, the influent to the plant was full of grit and sludge from the mains. The sludge obtained for testing on the first day was not typical of this particular plant.

The schedule of work was heavy and the thickening tests were not performed until the last day. Thickening data was only collected in 2-hour tests instead of 4-hour and 24-hour final. All thickening rates are reported for intervals within a 2-hour settling period.

POLYMER SCREENING TESTS

Figure 2 shows a typical polymer screening test plot used for selecting polymers and polymer dosing. On this particular plot it is shown that the trickling filter sludge was conditioned with a cationic polymer Calgon WT-2660, cationic Purifloc C-41, anionic A-23 Purifloc, and anionic 837-A Magnafloc in separate tests and doses. The two cationic polymers were more effective than the anionic types. Especially useful was the Calgon WT-2660. This polymer was also most efficient for P-TF-C and P-TF-A sludges. While testing with the alum sludge TF-A, it was found that the anionic 837-A was most effective and that the Calgon WT-2660 was also somewhat useful.

SPECIFIC RESISTANCE TESTS

The specific resistance tests were run on all sludges. A considerable number of tests were attempted, but it was found that the sludge could not be filtered without proper conditioning. The values obtained are reported in the summary table (Table 1). Since the compressibility values for sludges are obtained from specific resistance testing, the sludge was likewise conditioned prior to testing. Values for compressibility also appear in Table 1.

VACUUM FILTRATION

All vacuum filtration results are those obtained through filter leaf testing simulating operation of a continuous rotary vacuum filter. It was found that sludge conditioning was necessary to obtain a reasonable yield and cake thickness. The results of this testing are most effective in graphic presentation of actual filter yields (Figures 3 & 4). All sludges were conditioned with a Calgon cationic polymer, WT-2660. The primary trickling filter alum and control sludges gave similar yields (ca. 1.0 lb solid/ft^2-hr) at cycle times of 5 and 6 minutes respectively. When the cycle time was decreased to 2 minutes the P-TF-A yield was increased to 3.6 lb. solids (ft^2-hr). The trickling filter control sludge was conditioned with 20 lb. polymer/ton of solids. The filter leaf yield was approximately 3.0 lb. solids/ft^2-hr. The trickling filter alum sludge was not filterable with the leaf. Even with a considerable amount of polymer 20 lb. polymer/ton of dry solids, the particle size was far too small to form a cake on the filter medium.

RESULTS OF THICKENING

Only two sludges were used for thickening studies. The primary sludges were not tested because they were already rather thick (3-4%) when sampled. It was observed qualitatively that they did not settle noticeably after several hours standing. Settling curves for the trickling filter control (TF-C) and alum sludge (TF-A) are presented graphically in Figures 5 and 6. Both control and alum sludges were thickened with no chemical thickening aid and again with 3.3 lb. polymer per ton of dry solids. As can be seen on both graphs, the polymer is very effective, especially with the alum sludge. Although design data cannot be obtained on such thickening curves, the data can be compared by settling velocity obtained from the slope at the transition zone. The trickling filter control sludge rate was 0.21 ft/hr for no chemical aid and 0.43 ft/hr for the sludge with chemical aid. The alum sludge with no chemical added gave a rate of 0.14 ft/hr and with chemical the rate was 1.82 ft/hr.

DISCUSSION OF RESULTS

To summarize the results of testing, the most significant finding was that the trickling filter alum sludge (TF-A) was not filterable with a vacuum filter leaf, even after treatment with high levels of chemical conditioning agent. It was also found that there was little difference between the primary-trickling filter sludge mixture from the control plant and the primary-trickling filter sludge mixture from the alum-dosed plant. In general, it was found that a cationic polymer was successful for aiding the dewaterability of all sludges encountered at the UNC wastewater plant. The primary sludges could not be thickened, neither could the trickling filter sludges with and without alum. However, with proper conditioning, the secondary sludges were easily thickened.

A summary of past data concerning sludge production was made available to us by Dr. Francisco and appears in Table 2. Column 1 in the tabulation represents the control or conventional side of the plant and column 2 is the test side which is receiving alum. The data in the first eight rows are for plant flows equal on side 1 and 2. From the data, it is clear that the sludge volume is greater in the test plant than the conventional system. Also the sludge mass in lb/MG is greater for the alum addition. The data was calculated for lb. of addition solids/lb. of alum used. The average turned out to be 4.75 lb. sludge/lb. Al or 0.43 lb. sludge/lb. alum (9.1% Al).

TABLE 1

Sludge Characteristics: Chapel Hill Field Test

	SLUDGE TYPE			
	TF-C	TF-A	P-TF-C	P-TF-A
Date of Test (mo./da./72)	9/8	9/8	9/7	9/7
Original Solids (mg/l)	595	750	39,000	30,000
Solids after 24 hr. continuous thickening (mg/l)	20,600	7,700	*	*
Filtrability Tests (at optimum polymer dose)				
$r_{av} \times 10^{-11}$, at 15" Hg (cm/g) **	1.58	47.0	8.36	2.55
Compressibility	0.51	0.98	-	0.53
Filter Leaf Test				
Yield (lb/hr-ft^2)	2.11	0.20	2.94	3.60
Cycle Time (min)	2	2	4	2
Polymer				
Type	WT-2660	837A	WT-2660	WT-2660
Optimum dose #/ton solids	4	16	2	3

*Not Thickened

** To convert to sec^2/g, divide by 980.

TABLE 2

Solids Data UNC Waste Water Research Center
Mason Farm Wastewater Treatment Plant, Chapel Hill, N.C.

Date	Alum dose mg/l	Influent Flow MGD * 1	Influent Flow MGD 2	Influent SS mg/l	Effluent S. S.* 1	Effluent S. S.* 2	Prim. Sludge Pump. gal/day 1	Prim. Sludge Pump. gal/day 2	Prim. Sludge % Solid 1	Prim. Sludge % Solid 2	Prim Solid lb/MG 1	Prim Solid lb/MG 2	Second. Sludge Flow MGD 1	Second. Sludge Flow MGD 2	Secondary Sludge S.S. mg/l 1	Secondary Sludge S.S. mg/l 2
1/25-2/13/72	189	1.43	1.43	167	41	30	6140	7763	4.2	4.5	1552	2033	0.273	0.303	306	590
2/15-2/25/72	163	1.47	1.47	175	57	29	6250	8950	2.6	3.2	927	1619	0.273	0.303	450	567
2/26-3/10/72	163	1.38	1.38	198	59	30	6417	8708	4.5	4.0	1780	2117	0.273	0.303	656	642
3/10-3/19/72	201	1.16	1.16	239	59	28	6490	8470	3.8	4.1	1742	2457	0.273	0.303	317	646
3/30-3/26/72	144	1.51	1.51	258	69	45	6521	8721	3.6	4.8	1266	2264	0.273	0.303	503	567
3/27-4/6/72	181	1.51	1.51	245	77	38	6600	8400	4.2	3.9	1495	1860	0.273	0.303	559	1097
4/7-4/21/72	177	1.54	1.54	320	74	49	6600	8030	4.8	3.8	1654	1765	0.273	0.303	365	955
4/25-5/25/72	197	1.41	1.41	268	56	24	6898	8922	4.0	3.9	1515	1961	0.273	0.303	481	591
6/3-6/19/72	251	1.50	0.73	310	72	20	6521	8044	4.2	2.7	1480	2448	0.273	0.303	439	586
6/24-7/11/72	254	1.73	0.45	229	46	20	7761	5243	3.1	4.2	1293	3083	0.273	0.303	318	341

* 1 Denotes operation of Control Plant

2 Denotes operation of Alum Dosed Plant

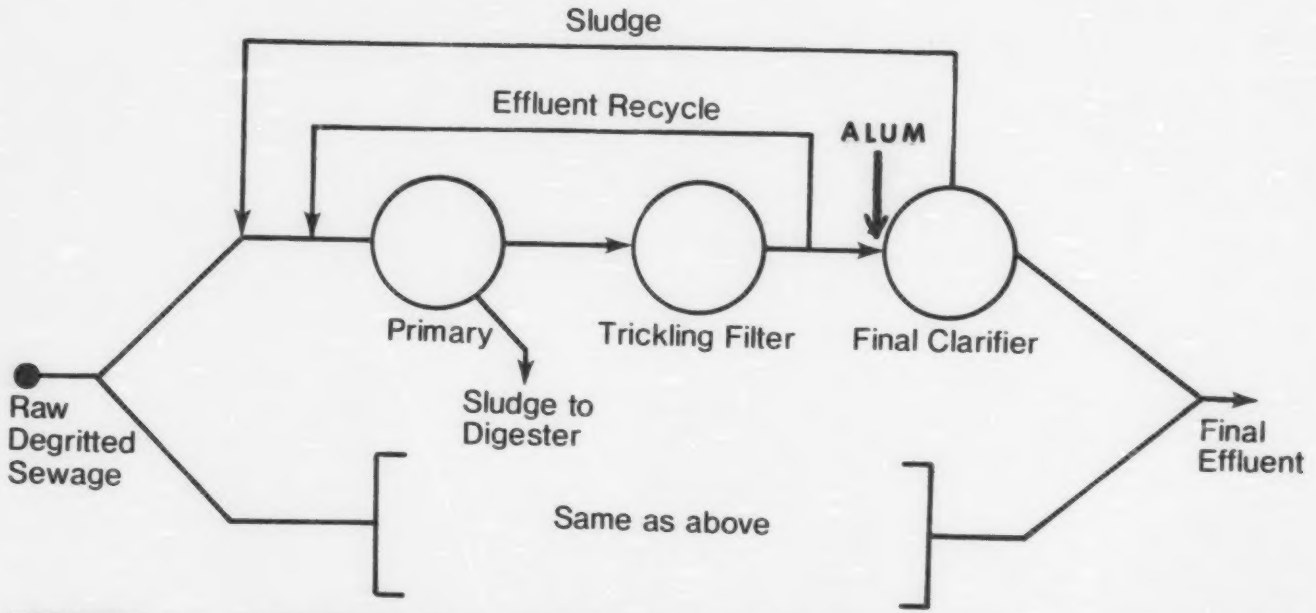

Sludge
Effluent Recycle
ALUM
Raw Degritted Sewage
Primary
Sludge to Digester
Trickling Filter
Final Clarifier
Final Effluent
Same as above

FIGURE 1 SCHEMATIC REPRESENTATION OF CHAPEL HILL PLANT

FIGURE 2

POLYMER CONDITIONING OF TRICKLING FILTER CONTROL SLUDGE

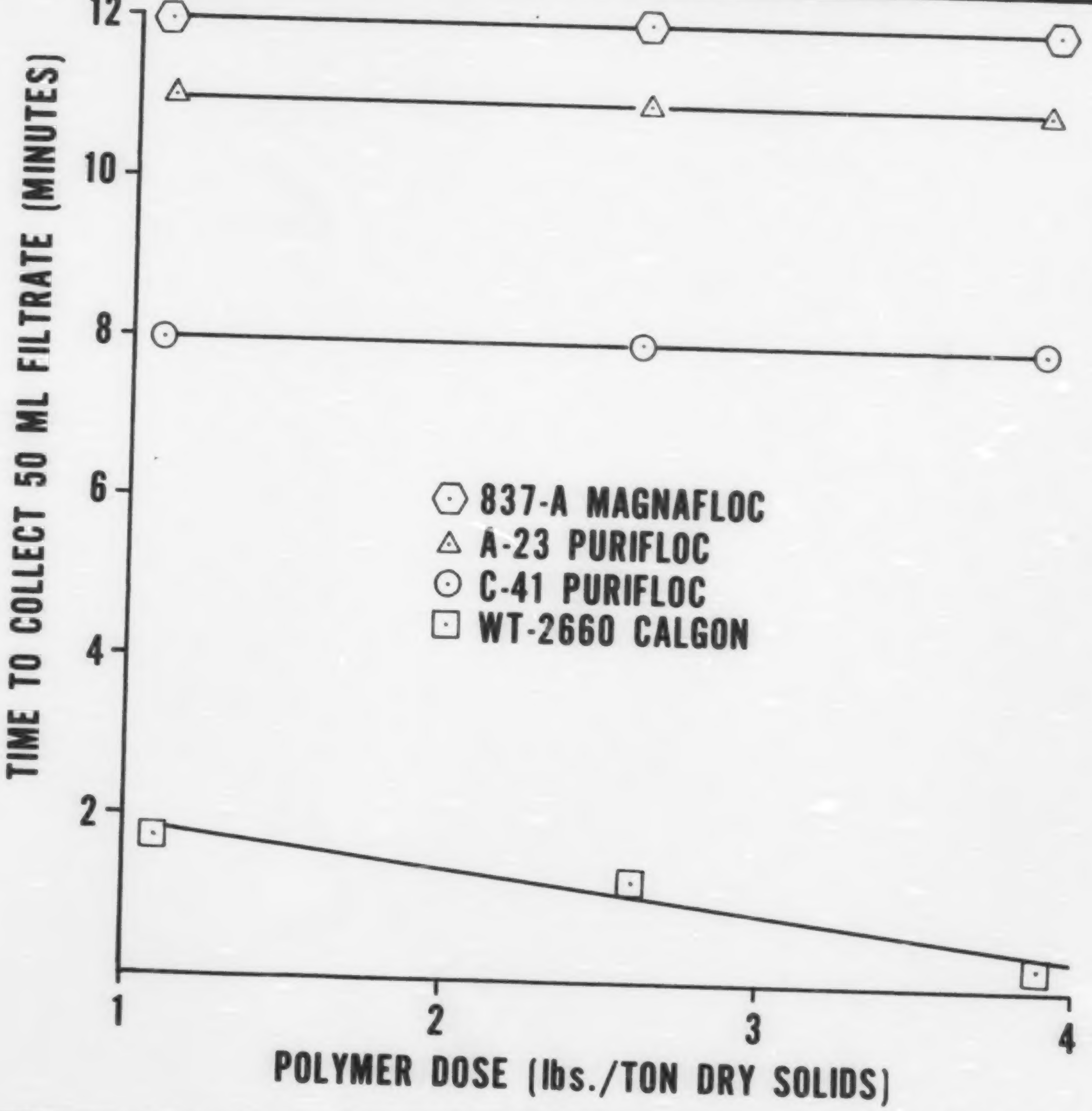


FIGURE 3

FILTER LEAF RESULTS: SLUDGE FROM CONTROL PLANT

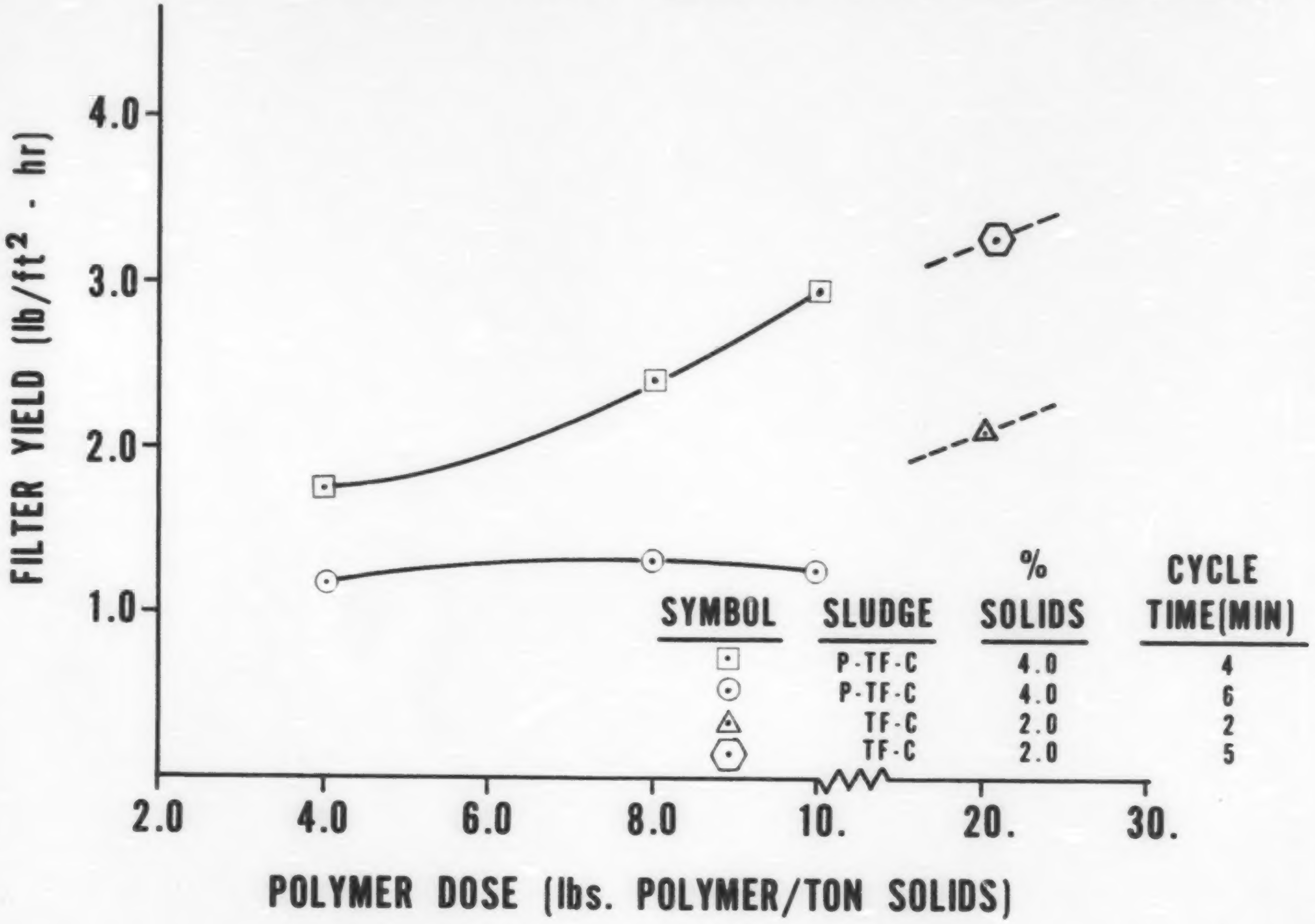


FIGURE 4
FILTER LEAF RESULTS: SLUDGE FROM ALUM DOSED PLANT

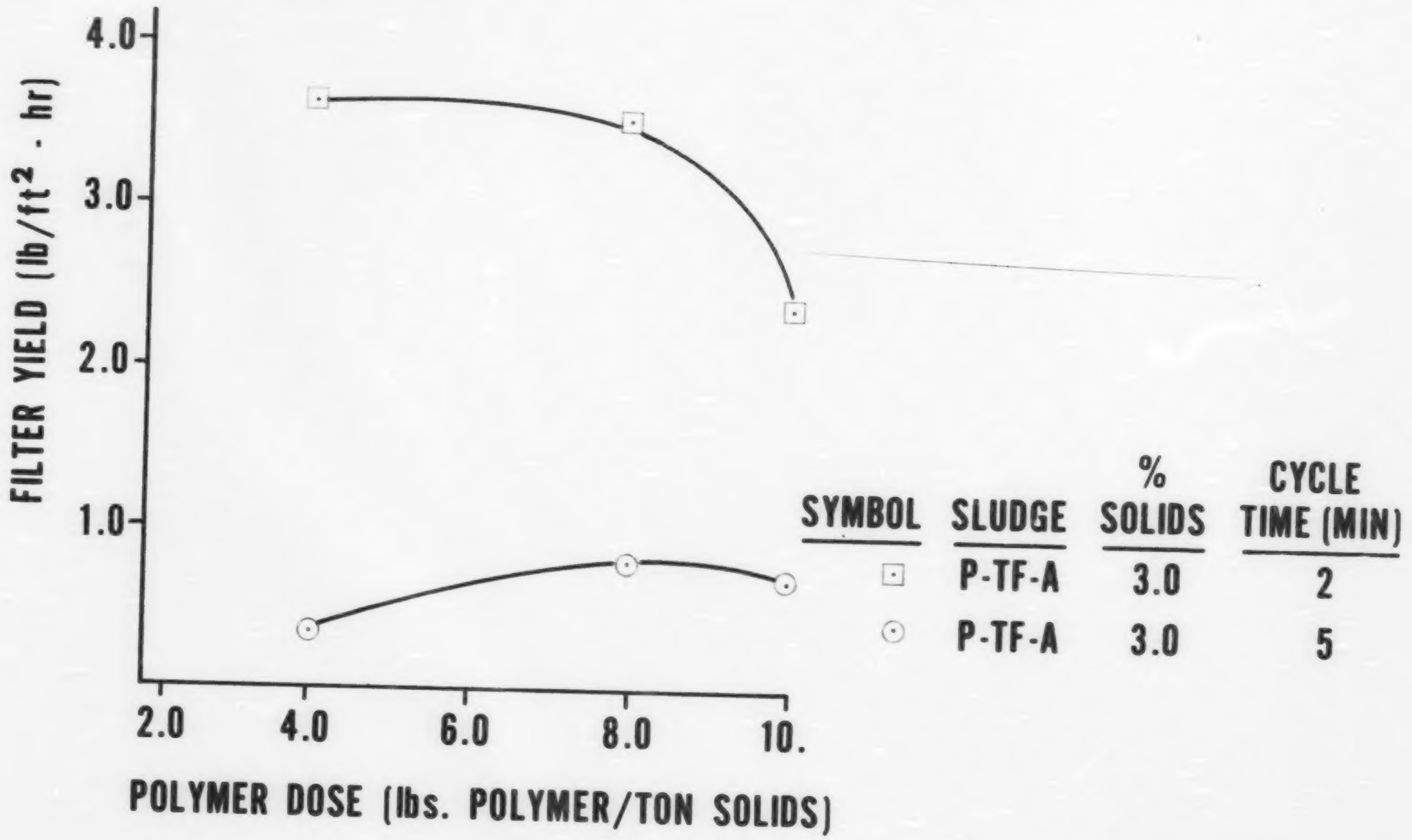


FIGURE 5

THICKENING TRICKLING FILTER-ALUM SLUDGE

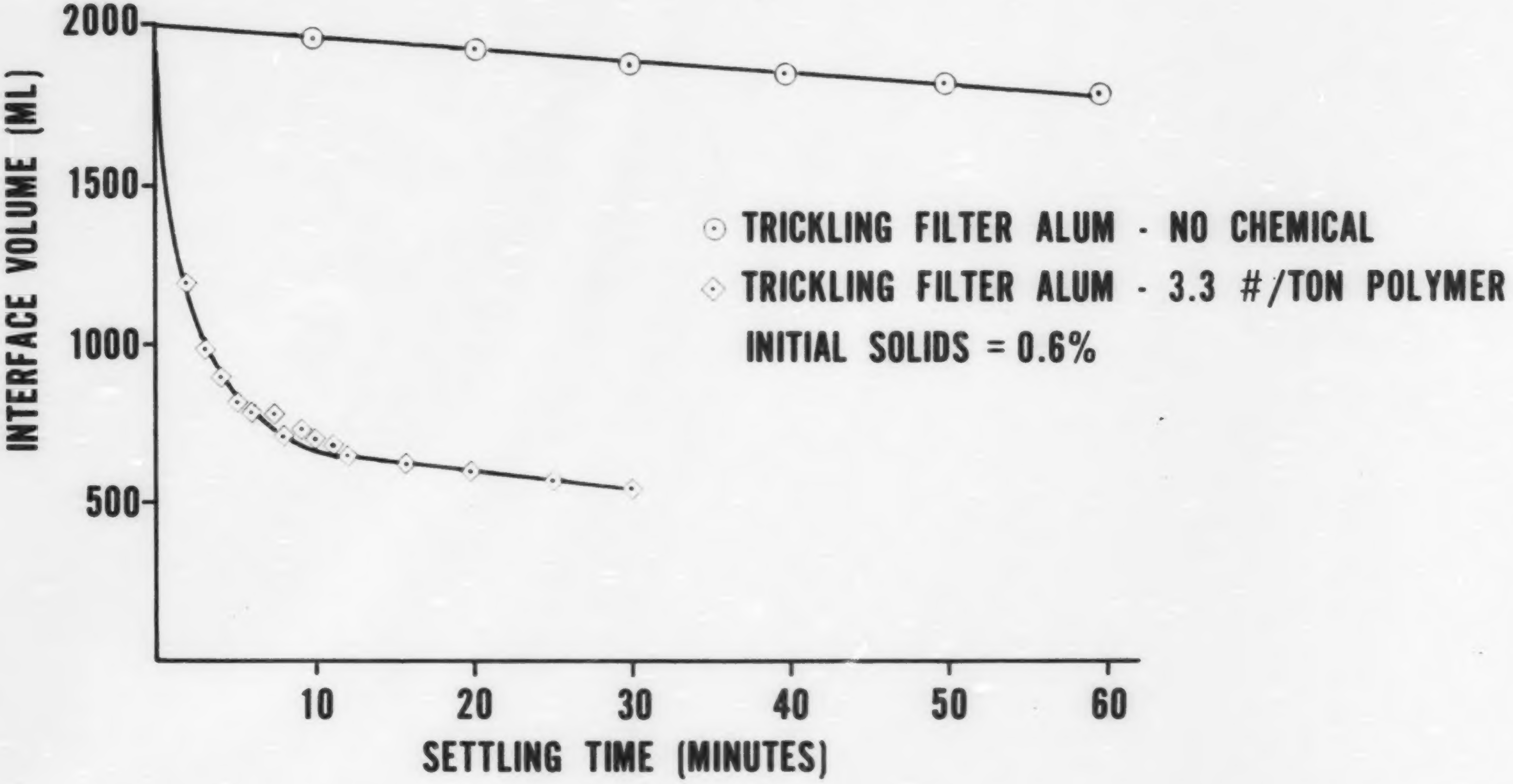


FIGURE 6

THICKENING TRICKLING FILTER CONTROL SLUDGE